BURNS COOLEY DENNIS, INC.

GEOTECHNICAL AND MATERIALS ENGINEERING CONSULTANTS

OPTIMIZING MISSISSIPPI AGGREGATES FOR CONCRETE BRIDGE DECKS

State Study 231

Project No. 105803 153000

and

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Curing Method Influence on Shrinkage of Gravel Aggregate Concrete

Prepared for
Mississippi Department of Transportation

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16. Abstract:

AASHTO M 43 "Standard Specification for Sizes of Aggregate for Road and Bridge Construction" addresses particle size distribution of material included in various maximum nominal size aggregates. This particle size distribution requires additional processing such as screening, separating, and recombining to meet AASHTO M 43 or the Mississippi Department of Transportation's particle size distribution requirements. Specifiers of concrete mixtures have utilized additional requirements on aggregates by placing upper and lower limits on combined percent retained on individual sieves. MDOT has recently utilized this concept by introducing similar limits on aggregate gradations used in concrete for bridge decks. This research project investigates the workability and shrinkage performance of concrete containing aggregate gradations not meeting these requirements and compares this performance to concrete containing aggregate gradations meeting MDOT's requirements for bridge decks.

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Abstract

Coarse and fine aggregates make up approximately 75 percent of the volume of concrete with the remaining volume made of cementitious paste. Cementitious paste is comprised of cementitious materials, water, air, and admixtures. AASHTO M 43 “Standard Specification for Sizes of Aggregate for Road and Bridge Construction” addresses aggregate particle size distribution of material included in various maximum nominal size aggregates. This particle size distribution requires screening, separating, and recombining to meet AASHTO M 43 or the Mississippi Department of Transportation’s (MDOT) particle size distribution requirements. Specifiers of national standards have utilized additional requirements on aggregates by placing upper and lower limits on combined percent retained on individual sieve sizes. MDOT has recently utilized this concept by introducing similar requirements on aggregates used in concrete for bridge decks for use on a limited number of projects to ascertain the value of requiring these limits. Concrete producers have found that using some aggregate sources to meet these requirements may be economically easier to use than other aggregate sources. If these requirements for aggregate gradations are implemented in construction projects state-wide, there should be documented benefits associated with having strict control over aggregate particle size distribution. These benefits may include higher strength, lower length change (reduced shrinkage and shrinkage cracks), or provide enhancements to placing and finishing operations. However, the benefit of most interest is increased durability at decreased initial and maintenance costs. To our knowledge, no laboratory data has been generated to document these benefits as a function of particle size distribution of Mississippi gravel aggregates.

The purpose of this research was to explore aggregate gradations that are outside the limits of MDOT Class BD concrete and determine additional gradations that may be used to produce sufficiently workable, low shrinkage concrete made with Mississippi gravel. Thirty mixes were developed for this study to evaluate compressive strength, length change (expansion and shrinkage), and workability. Data generated in this study can be used by engineers to determine criticality of aggregate particle size distribution in producing durable bridge deck concrete.

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Chapter 1 – Introduction

Background

Reinforced concrete is commonly used in the design and construction of highway bridges. Durable concrete is critical for bridges to provide long service life and low maintenance costs. It is essential that high quality materials be used in concrete to meet these demands. Each ingredient must meet requirements established in construction material standards provided by the American Association of State Highway and Transportation Officials (AASHTO) or the American Society for Testing and Materials (ASTM) in an attempt to achieve high quality concrete. These materials must be proportioned to produce durable concrete. Low shrinkage is an important characteristic that can enhance durability of concrete structures. Aggregate properties must receive careful consideration when durable concrete is the goal. The purpose of this study was to explore aggregate gradations that are outside the limits of MDOT Class BD concrete and determine additional gradations that may be used to produce sufficiently workable, low shrinkage concrete.

Concrete is a composite material consisting of aggregates, cementitious materials, water, air, and admixtures. Concrete can be divided into two major components including aggregates and cementitious paste. The aggregate portion is comprised of various aggregate sizes through blending fine and coarse aggregates. Fine aggregates generally range in size from the smallest grain up to 3/8 in. (1). Fine aggregates occur naturally or may be manufactured during the production of crushed coarse aggregate. Coarse aggregates contain particles retained on the No. 16 sieve and up to 1 in. size or larger (1). Coarse aggregates can be gravel or crushed stone. Round uncrushed gravel with sizes up to 1 in. are abundant in Mississippi. Natural sands are also abundant making gravel aggregate concrete with natural sand common in Mississippi. Aggregates make up 60% to 75% of the total volume of concrete (1). The remaining 25% to 40% of the volume of concrete is void space in aggregates developed by the irregular shape of individual particles. This void space must be filled with cementitious paste.

Concrete experiences volume changes in both its plastic state and hardened state. These volumetric changes are relatively small compared to the entire volume of concrete and primarily occur in the cementitious paste portion of the mixture as shrinkage. This shrinkage occurs as a result of chemical shrinkage, autogenous shrinkage, settlement, and plastic shrinkage.

Chemical shrinkage is a reduction in absolute volume of solids and liquids in cement paste that result from cementitious materials reacting with water. Portland cement and water occupy more volume in their individual state than when they are chemically combined (1). Consequently, as concrete sets and gains strength during hydration its volume shrinks.

Autogenous shrinkage occurs as water in the pores of the cementitious paste is consumed by hydration. This phenomenon is also known as self-desiccation (2). This shrinkage is much less than the absolute volume changes of chemical shrinkage (1). It is more prominent in concrete with high cementitious contents and low water contents having a water to cement ratio less than 0.42 (2). This additional consumption of water by hydration causes less volume and shrinkage in the cementitious paste. The water cement ratio (w/c) used in this study was 0.45 except for Mix 30 which used a w/c ratio of 0.473. Therefore, autogenous shrinkage was minimized in this study because of the w/c ratio.

Settlement also contributes to volume shrinkage. Settlement occurs as heavier solids in concrete mixtures settle and water rises. This water either evaporates or is otherwise removed from the concrete mixture causing a reduction in the volume of concrete. This reduction of water causes shrinkage in the overall volume of concrete.

Plastic shrinkage is a combination of chemical shrinkage, autogenous shrinkage, and rapid evaporation while the concrete is still in a plastic state. Plastic shrinkage is often attributed to surface cracking that can occur during final finishing operations. Plastic shrinkage was not considered in this study because rapid evaporation was prevented by using a moist room, water curing tank, and/or liquid membrane.

Hardened concrete also experiences volume changes and may be in the form of expansion and shrinkage with changes in moisture and temperature. When external water is available to replace water that is consumed by chemical shrinkage, expansion occurs. Additionally, expansion will occur when the moisture content in hardened concrete is increased by wetting. While concrete expands and contracts with changes in temperature and moisture, the overall tendency of concrete is to shrink. As hardened concrete dries due to the relative humidity of air being lower than the relative humidity of the concrete, drying shrinkage occurs. Drying shrinkage is documented in this study.

When shrinkage of concrete is restrained, shrinkage cracks can occur. Concrete shrinkage is restrained by supporting subgrade/subbase materials or from reinforcing steel and other structural elements. A combination of shrinkage of concrete materials and restraint is the mechanism that produces cracking. This restraint of shrinkage causes cracks to form as restrained shrinkage stresses exceed the strength of the concrete. Reinforcing steel is designed to resist tensile stresses in the concrete that are induced by imposed loads. It is also designed to hold faces of shrinkage cracks together. These shrinkage cracks are expected and included in the design of reinforcing steel. Even though shrinkage cracks are considered in reinforced concrete design, they should be minimized. These cracks provide channels for water and chloride ions to get to and corrode the reinforcing steel. They also provide openings for sulfates and other chemicals that can cause deterioration of the concrete.

Low cracking is a characteristic critical to durable concrete bridge decks. Bridge decks that exhibit minimal cracking will produce bridge decks with the longest service life and lowest maintenance costs. Specifications for concrete materials used in bridge decks must incorporate strategies to provide durability. MDOT has developed Class BD concrete for concrete bridge decks with a focus on durability. Class BD concrete addresses both concrete materials and construction procedures critical for durable concrete.

Aggregate gradation optimization is utilized in MDOT Class BD concrete. Reported benefits associated with aggregate gradation optimization include less cementitious paste required for a given slump, less shrinkage, greater strengths, adequate pumpability, and enhanced finishability (3). One goal for using aggregate gradation optimization is to fill voids in concrete with aggregate particles in lieu of cementitious paste. For a constant paste volume, this provides more cementitious paste for workability if it is not used for filling voids.

Selecting an aggregate gradation is a key part of the concrete mixture design process. The goal of achieving the ideal gradation in a concrete mixture is to create a mixture that meets all requirements for strength, durability, workability, segregation resistance, and shrinkage crack resistance. Practically, the goal of gradation optimization is to fill voids in the concrete matrix with aggregate instead of cement paste without sacrificing performance of the concrete. Ideally, the majority of the cementitious paste is utilized for workability of the mixture and bonding the aggregate together, not for filling voids.

Improved workability can result in increased durability which equates to lower life cycle cost of the concrete. Workability is affected by the interference of aggregate particles with each other. Good workability is achieved in part by spacing the aggregate particles apart with cementitious paste so that they do not interfere with each other (1). The quantity of water required to make a concrete mixture workable is dependent in part upon the surface area of the aggregate. The surface area is dependent upon the aggregate grading. Increased fine contents produce an increased in total surface area which requires more water to provide adequate workability. Thus, increased fine contents increase the water in a given concrete mixture which potentially increases the shrinkage and cracking potential.

There have been many attempts at guidelines for ideal gradations that address the aforementioned requirements for strength, durability, workability, segregation resistance, and shrinkage crack resistance. Two of the most popular guidelines include the "8-18 rule" and the Coarseness Factor Chart.

It was reported in the Concrete Construction that "A flippant comment Shilstone made at a 1990 meeting of ACI Committee 301, Specifications, resulted in what has come to be known as Shilstone's 18-8 rule" (4). The result of this comment was an industry accepted guide that the amount of aggregate retained on any standard sieve, except the coarsest and the finest, should be between 8 percent and 18 percent. **Note:** The "8-18" rule is actually "8-22" when using smaller maximum nominal size aggregates such as ¾ in. or 1 in. Shilstone never intended for this to be used as a specification, but says that this and thousands of other aggregate particle distributions can be used to create excellent concrete (4). The influence of the 8-18 rule can be seen in Table 1 which presents the combined percent of material retained on individual sieves used by ACI (5), KDOT (6), and MDOT (7) for maximum size aggregate up to 1 in.

Table 1 - Combined Percent Retained on Individual Sieves - ACI, KDOT, MDOT

	Combined Percent Retained on Individual Sieves												
	1-1/2 in.	1 in.	¾ in.	½ in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	Pan
ACI	NA	0-4	8-22	8-22	8-22	8-22	8-22	8-22	8-15	8-15	1.5-5	NA	NA
KDOT	0	2-6	5-18	8-18	8-18	8-18	8-18	8-18	8-15	5-15	0-5	NA	0-2.5
MDOT	0	2-6	5-22	8-22	8-22	8-22	8-22	8-18	8-15	5-18	0-6	0-5	0-2

ACI 302 “Guide for Concrete Floor and Slab Construction” provides for deviations from the 8-18 rule when there are limitations in locally available material. ACI 302 states “the following limitations should always be imposed:”. (5)

1. Do not permit the percent retained on two adjacent sieve sizes to fall below 5%;
2. Do not allow the percent retained on three adjacent sieve sizes to fall below 8%; and
3. When the percent retained on each of two adjacent sieve sizes is less than 8%, the total percent retained on either of these sieves and the adjacent outside sieve should be at least 13%.

The coarseness factor chart consist of two components include coarseness factor (CF) and workability factor (WF). An increase in CF indicates that the overall coarseness of the aggregate is increasing due to the gradation of the aggregates. An increase in WF indicates that the overall fineness of the aggregates is increasing due to the gradation of the aggregates. The CF chart has been successfully used to determine aggregate gradations that provide acceptable workability for concrete mixtures.

There are many sources citing the background, interpretation and alteration of the CF chart used for finding the ideal aggregate gradation for a concrete mixture. The original CF chart, shown in Figure 1, was developed by Shilstone with the purpose of identifying characteristics of a mixture such as: harshness, sandiness, excessive shrinkage, pumpability, finishing characteristics, degree of gap-grading, and proneness to segregation (3). The initial chart contained a trend bar. Concrete mixtures that plot within the trend bar, if created using gravel or cubical shaped crushed material, and well-graded natural sand, will require a minimum amount of water but may exhibit poor finishability and cannot be pumped (3).

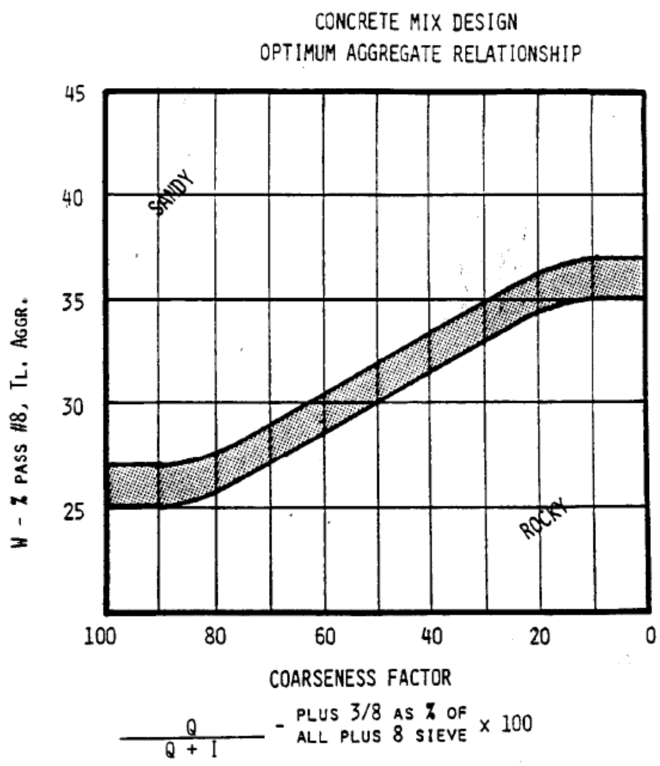

Figure 1 - The Original Shilstone Coarseness Factor Chart

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Revisions of the CF chart added Zones I through V as shown in Figure 2. These zones are described by Richardson in his paper "Aggregates Gradation Optimization-Literature Search" as follows (3):

"Zone I coarse, gap-graded , tends to segregate; Zone II well graded 1-1/2 in., best spot for everyday mixes, depending on use, Zone III ¾ in. and finer (pea gravel mixes), Zone IV: oversanded, sticky, Zone V rocky (may be suitable for mass concrete). The trend bar is relabeled "0" optimum but excellent control required. Zone II is divided into five areas: II-1 excellent but caution, II-2 excellent paving and slipform, II-3 high quality slab, II-4 good general, and II-5 varies to material and construction needs."

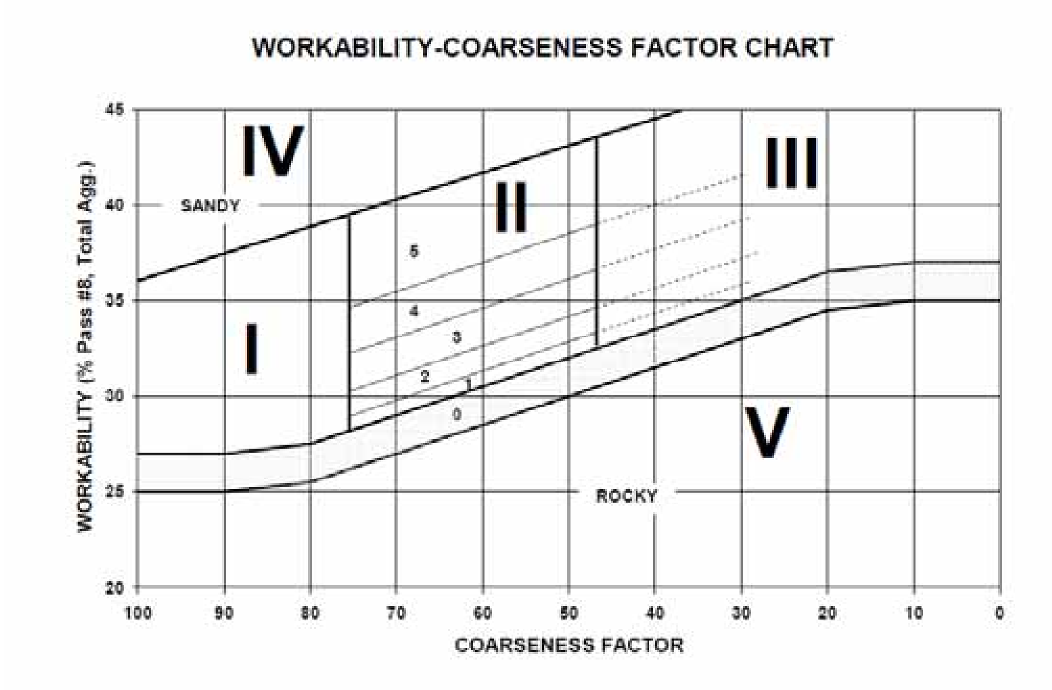

Figure 2 - Revised Shilstone Coarseness Factor Chart

Figure reprinted from (Richardson, 2005) by permission

Most of the validation of the CF chart tends to come from case history experience. One exception is a study by Joel (1990) that varied ASTM C33 fine aggregate and No. 67 coarse aggregate between allowable limits (8). The chart did a "reasonable" job of sorting out which mixtures are high in paste and which ones are rocky. A study by Wilson and Richardson (2001) examined the effect of adding intermediate size aggregate to a typical Missouri Department of Transportation gap graded mix (9). The chart correctly predicted the non-cohesive, segregation susceptibility of the mixture by its position in Zone II (3).

Figure 3 provides an example of a coarseness factor chart similar to the one presented in ACI 302 superimposed with an ellipse indicating MDOT's limits for combined aggregate gradations.

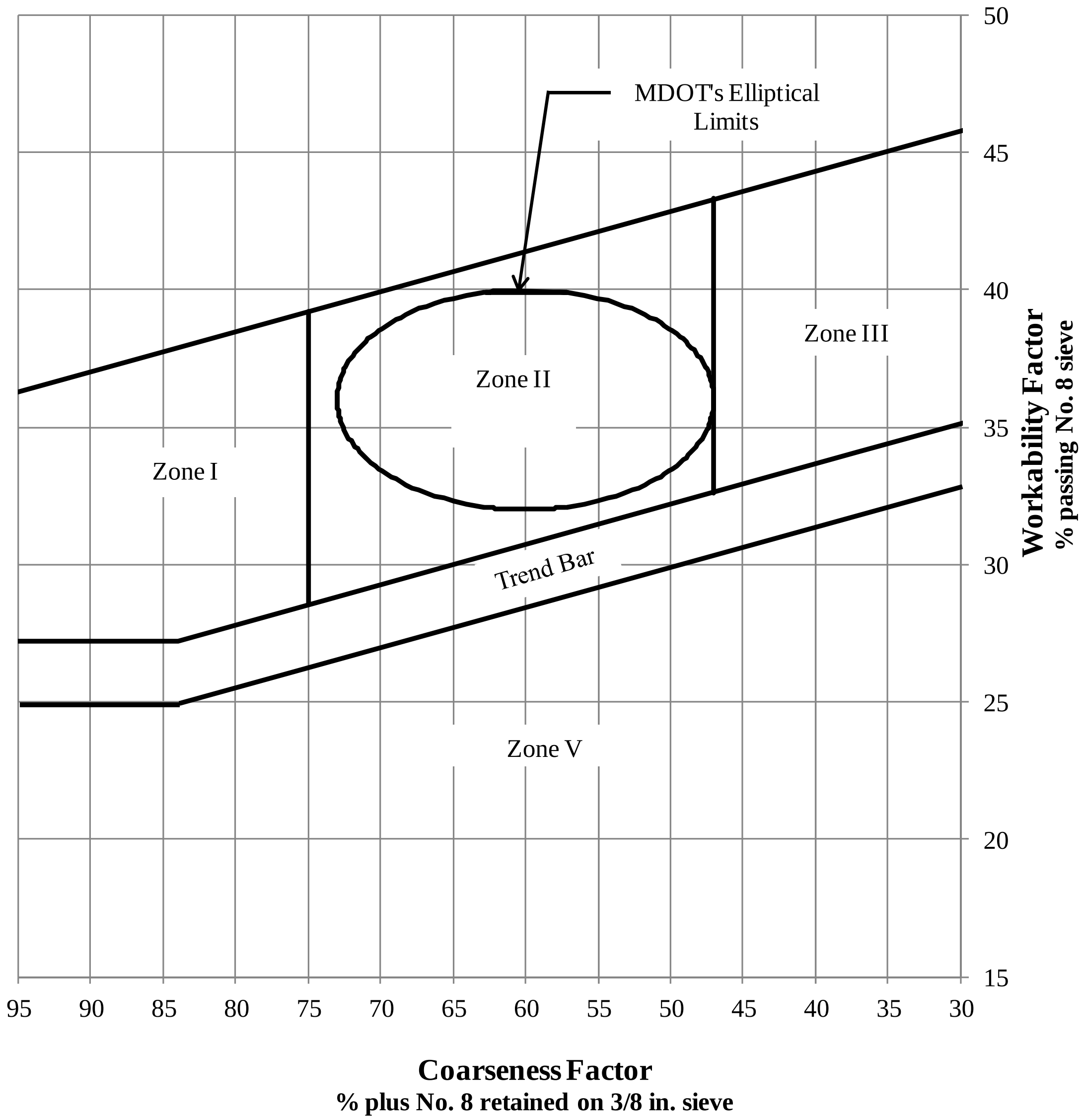

Figure 3 – Modified Coarseness Factor Chart Superimposed with MDOT's AWF/CF Limits

Concrete mixtures proportioned in this study include concepts of coarseness factor (CF), workability factor (WF), and adjusted workability factor (AWF). The adjusted workability factor accounts for any excess or deficiency of fines contributed by the cementitious materials in the mixture. ACI 302 defines CF (x-axis) as the percent of the combined aggregate that is retained on the No. 8 sieve that is also retained in the 3/8 in. ACI 302 defines the WF (y-axis) as the percent combined aggregate that passes the No. 8 sieve. MDOT's "Concrete Field Manual" contains Equation 1 for CF, Equation 2 for WF, and Equation 3 for AWF (10).

$$CF = \frac{Cumulative\ \%\ retained\ on\ 3/8\, in.\ sieve}{Cumulative\ \%\ retained\ on\ No.8\ sieve} * 100 \tag{1}$$

$$WF = \frac{Cumulative\ \%\ passing\ No.8\ sieve}{Cumulative\ \%\ retained\ on\ all\ sieves} * 100 \tag{2}$$

$$AWF = WF + \frac{2.5}{sack} * \left[\frac{Total\ weight\ of\ cementitious\ materials}{94 \frac{lb}{sack}} - 6\ sack \right] \tag{3}$$

MDOT additionally provides upper and lower limits on the CF and AWF. See equations 4 through 7 for MDOT limits for CF and AWF (7).

$$AWF_{upper\ limit} = 36 + \sqrt{16 - \left(\frac{4}{13}\right)^2\ X\ (CF - 61)^2} \tag{4}$$

$$AWF_{lower\ limit} = 36 - \sqrt{16 - \left(\frac{4}{13}\right)^2\ X\ (CF - 61)^2} \tag{5}$$

$$CF_{upper\ limit} = 61 + \sqrt{169 - \left(\frac{13}{4}\right)^2\ X\ (AWF - 36)^2} \tag{6}$$

$$CF_{lower\ limit} = 61 - \sqrt{169 - \left(\frac{13}{4}\right)^2\ X\ (AWF - 36)^2} \tag{7}$$

MDOT engineers desire concrete used in bridge deck construction to be durable. Durability of concrete is among other things a function of the amount of shrinkage associated with specific concrete mixtures. Specifiers can implement strategies to reduce shrinkage cracking by utilizing aggregate gradation optimization. Little laboratory data was available for MDOT engineers to formulate specifications for aggregate gradations using Mississippi gravel aggregates. State Study 231 "Optimizing Mississippi Aggregates for Concrete Bridge Decks" documents workability, shrinkage, and compressive strength characteristics of concrete made with twenty-nine unique aggregate gradations using Mississippi gravel aggregates.

Objective

There were two objectives associated with this study. One objective was to determine aggregate gradation(s) that provide increased slump when compared to control mixtures having their CF and AWF plot within MDOT's elliptical limits on the modified CF chart. The increased slump produced by reduced aggregate particle interference allows the concrete mixture designer to decrease the amount of cementitious materials and water in the mixture while maintaining the same water w/c ratio and acceptable workability. The second objective was to determined aggregate gradations that produce the least amount of void space between aggregate particles. Reducing cementitious paste in concrete by reducing water or reducing voids may result in less shrinkage and cracking in concrete.

Approach

Twenty-nine concrete mixtures were developed with specific combined aggregate gradations to explore all applicable areas of the modified CF chart. Mixtures with a combined aggregate gradation plotting within MDOT's elliptical limits on the modified CF chart and individual sieve limits were considered to be the control mixtures. Control mixtures were designed with combined aggregate gradations that placed CF, AWF, and individual sieve limits of these mixtures within MDOT's elliptical limits on the modified CF chart presented in Figure 3.

Mixtures in this study were proportioned to produce a 3 in. ± ½ in. slump without chemical admixtures or supplemental cementitious materials (SCM's). Aggregates were oven dried and separated into individual size fractions to meet combined gradations needed for this study.

Aggregate gradations were developed to produce coarseness and workability points in all areas of the modified CF chart. As points were developed throughout the chart, slump either increased or decreased indicating that the aggregate gradation was either increasing workability (increasing slump) or decreasing workability (decreasing slump). As slump increased, water and portland cement were reduced to maintain a 3 in. ±½ in. slump. As slump decreased, water and portland cement were added to maintain a 3 in. ±½ in. slump.

Testing was also performed on the hardened concrete to determine the influence of CF and AWF on compressive strength and length change. The test method used to determine compressive strength was AASHTO T 22 / ASTM C 39 “Standard Test method for Compressive Strength of Cylindrical Concrete Specimens.” The test method used to measure length change was AASHTO T 160 / ASTM C 157 “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete.” These tests were conducted on each of the mixtures.

Length change according to AASHTO T 160 / ASTM C 157 uses a comparator accurate to the nearest 0.0001 in. to measure the length change of 4 in. by 4 in. by 11 ¼ in. long concrete prism specimens compared to a standard reference steel bar. Length change measurements extended over a 476 day period including 28 days of soaking and 448 days of drying for each specimen. Expansion occurred while specimens remained in a water bath for the first 28 days. The specimens were then placed in a temperature and humidity controlled room after the first 28 days where shrinkage began. Specimens remained in this room until testing was completed. Length change resulting from chemical shrinkage, autogenous shrinkage, and drying shrinkage was calculated for each mixture. Chapter 4 “Laboratory Testing” provides a detailed description of test procedures and length change calculations.

A total of thirty mixtures were tested to provide data for this study. Table 2 provides a general description of each mixture and Figure 4 presents locations of each mixture on the modified CF factor chart. Mixtures located within MDOT’s elliptical limits on the modified CF chart and individual sieve limits were selected to serve as benchmarks (i.e., controls) to compare the performance of the other mixtures to typical performance. Data generated in this study were used to evaluate the influence of aggregate gradations on workability and paste content.

Table 2 – Experimental Mixtures

Mix No.	Slump Requirement (in.)	Water Cement Ratio	Coarseness Factor (CF)	Workability Factor (WF)
1	2 ½ to 3 1/2	0.45	64.5	33.1
2	2 ½ to 3 1/2	0.45	61.0	36.0
3	2 ½ to 3 1/2	0.45	59.0	35.8
4	2 ½ to 3 1/2	0.45	58.9	35.7
5	2 ½ to 3 1/2	0.45	39.2	23.5
6	2 ½ to 3 1/2	0.45	40.7	46.1
7	2 ½ to 3 1/2	0.45	80.0	30.0
8	2 ½ to 3 1/2	0.45	80.0	46.1
9	2 ½ to 3 1/2	0.45	58.2	23.4
10	2 ½ to 3 1/2	0.45	58.2	41.5
11	2 ½ to 3 1/2	0.45	85.0	35.0
12	2 ½ to 3 1/2	0.45	36.3	37.1
13	2 ½ to 3 1/2	0.45	72.5	35.0
14	2 ½ to 3 1/2	0.45	70.0	40.0
15	2 ½ to 3 1/2	0.45	50.0	40.0
16	2 ½ to 3 1/2	0.45	70.0	30.0
17	2 ½ to 3 1/2	0.45	50.0	30.0
18	2 ½ to 3 1/2	0.45	47.5	35.0
19	2 ½ to 3 1/2	0.45	70.0	25.0
20	2 ½ to 3 1/2	0.45	50.0	25.0
21	2 ½ to 3 1/2	0.45	80.0	40.0
22	2 ½ to 3 1/2	0.45	40.0	40.0
23	2 ½ to 3 1/2	0.45	40.0	30.0
24	2 ½ to 3 1/2	0.45	60.0	40.0
25	2 ½ to 3 1/2	0.45	60.0	30.0
26	2 ½ to 3 1/2	0.45	90.0	35.0
27	2 ½ to 3 1/2	0.45	60.0	45.0
28	2 ½ to 3 1/2	0.45	90.0	30.0
29[1]	As Required	0.45	64.5	33.1
30[2]	As Required	0.47	59.0	35.8

Notes:

1. Mix 29 was a repeat of Mix 1 except it used a different aggregate grading to determine the influence of the shape of the combined individual percent retained chart on concrete properties.
2. Mix 30 was a repeat of Mix 3 and used to evaluate the impact of adding 1.5 gallons of water per cubic yard of concrete while holding all other proportions constant.

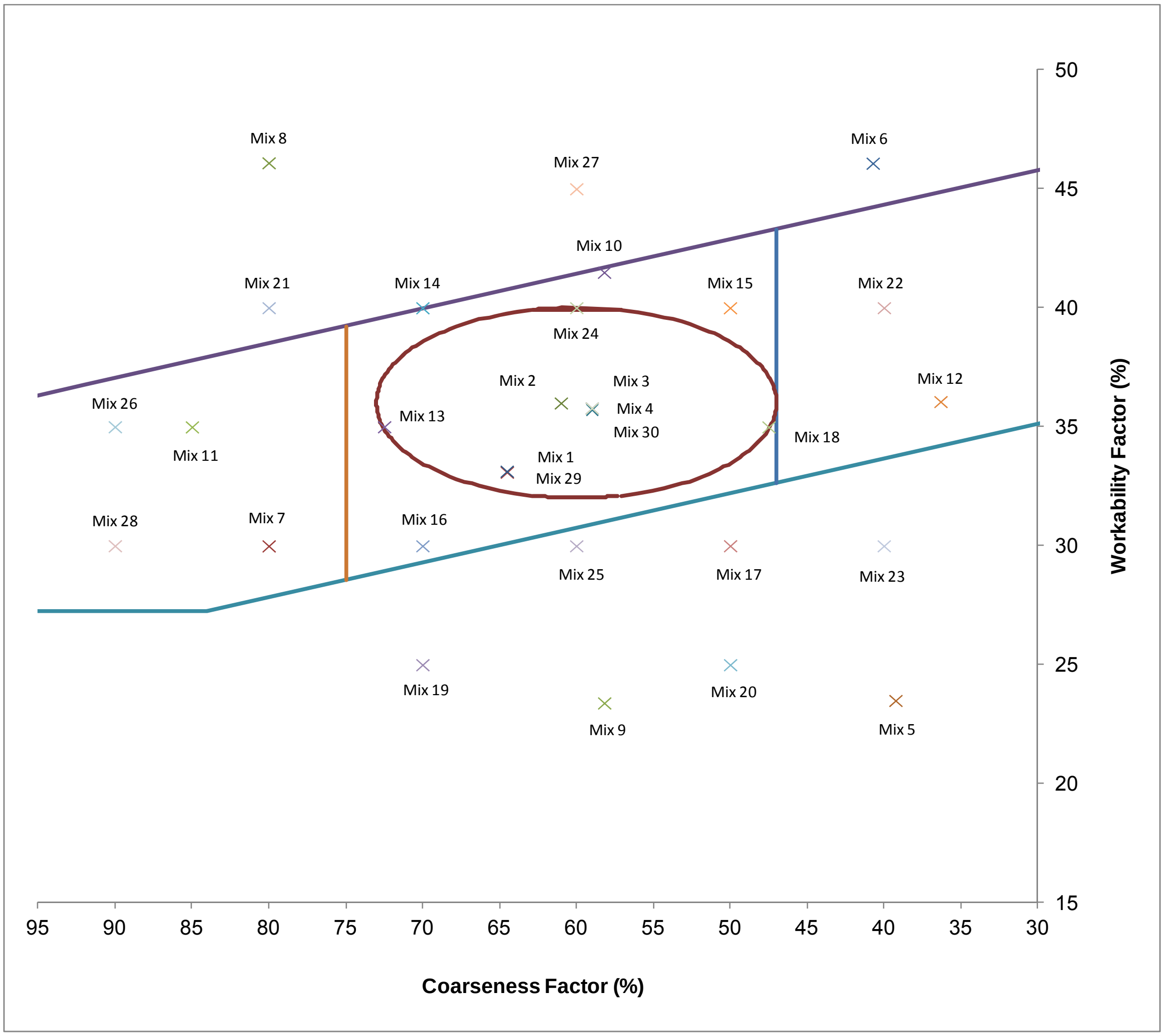

Figure 4 – CF and WF of Experimental Mixes Plotted on Modified Coarseness Factor Chart

Chapter 2 - Materials

Portland Cement

Portland cement is hydraulic cement and acts as the primary cementing material in portland cement concrete. Type I portland cement meeting requirements of ASTM C 150 / AASHTO M 85 is hydraulic cement made to conform to specific chemical and physical property limits according to these specifications. These specifications provide for eight types of portland cement meeting various set time or exposure criteria. Type I LA (low alkali) portland cement was used in this study and is referred to herein as Type I. Only one source of Type I cement was used in this study.

Chemical and physical properties of the Type I portland cement used in this study were provided by the supplier and are presented in Table 3. The cement is from a source that is approved for use on MDOT projects.

Aggregates

The fine and coarse aggregate used in this study came from the same aggregate source. Multiple tests were performed on separate samples to determine sieve analysis, gravities, and absorption. The average results of the aggregate testing are presented in Table 4. The aggregates are from a source that is approved for use on MDOT projects.

All aggregates used in this study were oven dried for processing and batching the concrete mixtures. The aggregates were introduced to sieves of progressively smaller size in such quantities as to guard against overloading any individual sieve. Once reduced to individual size fractions, aggregates were stored in sealed buckets until they were introduced in the concrete mixtures. Sieving the aggregates down to individual size fractions facilitated mixing the aggregates into the required combinations of combined individual percent retained quantities.

Table 3 - Chemical and Physical Properties of Portland Cement Used in this Study

Chemical Properties	Results
Silicon Dioxide (SiO_2), %	19.6
Aluminum Oxide (Al_2O_3), %	5.5
Ferric Oxide (Fe_2O_3), %	3.0
Calcium Oxide (CaO), %	64.5
Magnesium Oxide (MgO), %	0.8
Sulfur Trioxide (SO_3), %	3.4
Loss of Ignition (LOI), %	2.3
Insoluble Residue, %	0.20
Free Lime, %	1.22
Alkalies (Na_2O equivalent), %	0.54
Carbon Dioxide (CO2), %	1.1
Limestone, %	2.6
CaCO3 in limestone, %	96
Tricalcium Silicate (C_3S), %	57
Dicalcium Silicate (C_2S), %	13
Tricalcium Aluminate (C_3A), %	9
Tetracalcium Aluminoferrite (C_4AF), %	9
Physical Properties	**Results**
Blaine Fineness, m^2/kg	382
325 Mesh (% passing)	92.0
Time of setting (Vicat) Initial Set, minutes	85
Time of setting (Vicat) Final Set, minutes	185
Time of Setting (Gillmore) Initial Set, minutes	140
Time of Setting (Gillmore) Final Set, minutes	235
Air Content, %	6.9
False Set, %	83
Normal Consistency, %	24.2
Autoclave Expansion, %	0.06
Expansion in Water, %	0.006
Compressive Strength, 1 day (psi)	2,610
Compressive Strength, 3 day (psi)	4,330
Compressive Strength, 7 day (psi)	5,220

Table 4 - Average Aggregate Properties

Sieve Size	No.57		No. 8		Sand	
	Individual % Retained	Total % Passing	Individual % Retained	Total % Passing	Individual % Retained	Total % Passing
1”	8.1	91.9	0.0	100.0	0.0	100.0
¾”	17.8	74.1	0.0	100.0	0.0	100.0
½”	26.7	47.4	0.0	100.0	0.0	100.0
3/8”	14.6	32.8	9.0	91.0	0.0	100.0
No. 4	28.8	4.0	79.1	11.9	1.3	98.7
No. 8	3.3	0.7	10.8	1.1	7.4	91.3
No. 16	0.3	0.5	0.4	0.7	8.8	82.5
No. 30	0.1	0.4	0.2	0.5	21.0	61.5
No. 50	0.1	0.2	0.2	0.2	48.3	13.3
No. 100	0.1	0.1	0.2	0.1	13.0	0.3
No. 200	0.0	0.5	0.0	0.5	0.2	0.5
FM	6.87		5.95		2.52	
Bulk Gravity (DRY)	2.477		2.488		2.628	
Bulk Gravity (SSD)	2.532		2.543		2.635	
Absorption %	2.202		2.204		0.260	

Chapter 3 – Mixtures

The influence of aggregate gradation on concrete's workability, compressive strength and length change is described herein based on laboratory test results and experience gained during production of thirty concrete mixtures. Mixes 1 through 28 were developed to produce a slump of 2 ½ to 3 ½ inches and a w/c of 0.45. The combined aggregate gradations and paste contents of these mixtures were adjusted as needed to explore all zones of the modified CF chart. Mix 29 was a repeat of Mix 1 using a different aggregate grading to determine the influence of the shape of the combined individual percent retained chart. Mix 30 was developed to evaluate the impact of adding 1 ½ gallons of water per cubic yard of concrete to a mixture while holding all other proportions constant.

Blending of Aggregates

The approach was to give each mixture a unique combined aggregate grading that when evaluated, in terms of CF and AWF, would be a fair representation of all zones of a modified CF chart. The aggregate proportions for the mixtures were derived in one of two ways; 1) natural aggregate blending, driven by each material's sieve analysis, or 2) manufactured blending, driven by the desired coarseness and workability targets. Table 5 presents descriptions of each mixture in terms of CF, WF, AWF, and method of blending.

Natural Blend Mixtures.

Natural blend mixtures used aggregate gradations as produced from the aggregate supplier. Blending these coarse and fine aggregates was all that was necessary to achieve the desired combined aggregate gradation. However, individual size fractions of the aggregates were separated to ensure precise proportioning. Eight of the studied mixtures are referred to as natural blends. These include mix numbers 1, 3, 5, 6, 9, 10, 12, and 30.

Manufactured Blend Mixtures.

The remaining twenty-two mixtures are referred to as manufactured blends. The aggregates in these mixtures were combined at the individual sieve retained level to achieve a predetermined final combined aggregate gradation. No. 57 gravel was used for the coarse sieve quantities, sand for the fine sieve quantities, and pea gravel for the No. 4 and No. 8 sieve quantities.

Table 5 – Experimental Mixtures – CF, WF, AWF, Blend

Mix No.	Coarseness Factor (CF)	Workability Factor (WF)	Adjusted Workability Factor (AWF)	Blend
1	64.5	33.1	32.1	Natural Blend
2	61.0	36.0	35.0	Manufactured Blend
3	59.0	35.8	34.8	Natural Blend
4	58.9	35.7	34.7	Manufactured Blend
5	39.2	23.5	22.5	Natural Blend
6	40.7	46.1	46.5	Natural Blend
7	80.0	30.0	27.9	Manufactured Blend
8	80.0	46.1	46.5	Manufactured Blend
9	58.2	23.4	22.4	Natural Blend
10	58.2	41.5	41.5	Natural Blend
11	85.0	35.0	32.9	Manufactured Blend
12	36.3	37.1	36.1	Natural Blend
13	72.5	35.0	32.9	Manufactured Blend
14	70.0	40.0	39.0	Manufactured Blend
15	50.0	40.0	39.0	Manufactured Blend
16	70.0	30.0	27.9	Manufactured Blend
17	50.0	30.0	27.9	Manufactured Blend
18	47.5	35.0	34.0	Manufactured Blend
19	70.0	25.0	22.9	Manufactured Blend
20	50.0	25.0	22.9	Manufactured Blend
21	80.0	40.0	39.0	Manufactured Blend
22	40.0	40.0	39.0	Manufactured Blend
23	40.0	30.0	28.6	Manufactured Blend
24	60.0	40.0	39.0	Manufactured Blend
25	60.0	30.0	27.9	Manufactured Blend
26	90.0	35.0	32.9	Manufactured Blend
27	60.0	45.0	45.4	Manufactured Blend
28	90.0	30.0	27.9	Manufactured Blend
29	64.5	33.1	32.1	Manufactured Blend
30	59.0	35.8	34.8	Natural Blend

Mix 1 - MDOT Paving Mix

Mix 1 was developed using MDOT's requirement for minimum coarse aggregate content for concrete paving. Figure 5 presents the combined percent retained chart for Mix 1. Section 501 "Portland Cement Concrete Pavement" of the MDOT's Specifications for Road and Bridge Construction requires a minimum coarse aggregate content for concrete pavements. The minimum limit of coarse aggregate is 72 percent of the volume of a cubic yard of concrete. The minimum dry weight of coarse aggregate per cubic yard of concrete is then calculated using Equation 8.

$$W_{CA} = 0.72 \; x \, 27 \; x \; DRUW \qquad (8)$$

Where:

W_{CA} = Weight of Coarse Aggregate

DRUW = Dry Rodded Unit Weight

The dry rodded unit weight of the No. 57 gravel used in this study was 103.4 pcf. Using this weight in Equation 8 gives a coarse aggregate weight of 2010 pounds for Mix 1 providing a coarse aggregate volume of 65.5 percent of the total aggregate volume. Table 6 presents mixture proportions used in Mix 1.

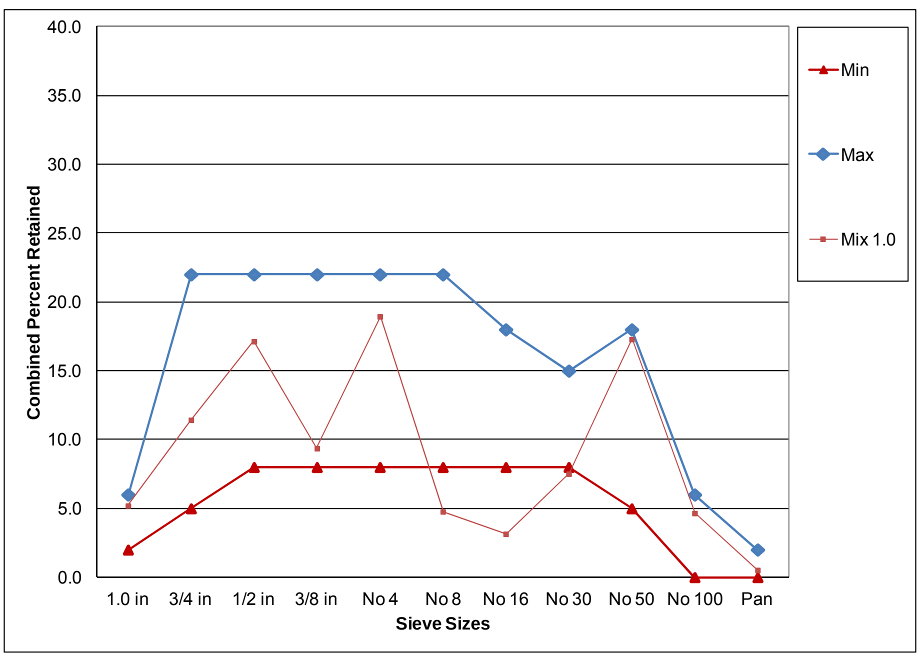

Figure 5 - Combined Percent Retained Chart - Mix 1

Table 6 – Mixture Proportions for Mix 1

Material	Dry Weights Per Cubic Yard (lbs.)	Absolute Volume (ft^3)
Cement	526.40	2.68
Coarse Aggregate	2010	13.00
Fine Aggregate	1123	6.85
Water	236.88	3.80
Air	NA	0.68

Mix 2 – Smooth Combined Percent Retained Chart

Mix 2 was developed by creating a smooth combined percent retained chart with values plotting near the middle of the 8-18 rule limits and forming the shape of a "hay stack." This chart is presented in Figure 6. The "hay stack" gradation of Mix 2 met MDOT Class BD requirements for combined percent retained on individual sieves except for exceeding the maximum of 2 percent retained in the pan. The excess of material in the pan for Mix 2 was 0.47 percent. In addition, MDOT's upper (denoted by Max) and lower limits (denoted by Min) for percent retained on individual sieves are shown in all combined percent retained charts shown herein for reference. Aggregate grading used in Mix 2 provided a CF and WF near the center of MDOT's elliptical limits on the modified CF chart before the workability factor was adjusted for fines contributed by the cement.

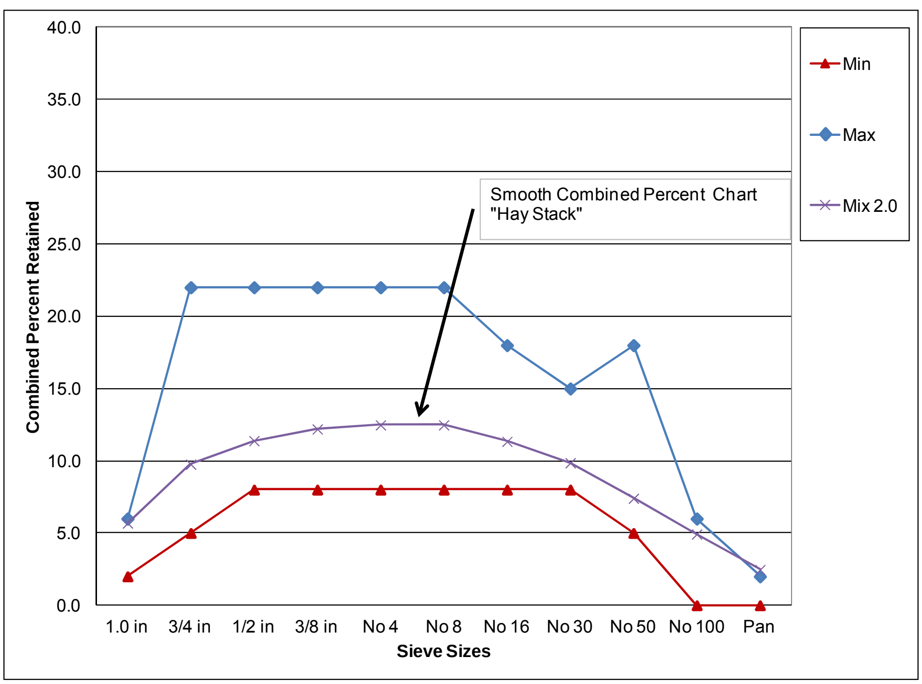

Figure 6 - Combined Percent Retained Chart - Mix 2

Mixes 3 and 4 - University of Kansas Aggregate Optimization

University of Kansas (KU) software was used to optimize the aggregate gradations for Mixes 3 and 4. KU's computer software is a Microsoft Excel Workbook, utilizing visual basic for applications, that performs the aggregate gradation optimization process. Available from www.iri.ku.edu, this application determines an optimized aggregate gradation based on combined coarse and fine aggregate individual percent retained and CF chart (11). The KU mixtures consist of user-selected aggregates combined in proportions suggested by the KU application to produce an "*ideal gradation*." This study employed No. 57, No. 8, and concrete sand in the increments suggested by the KU application. Figure 7 presents the combined percent retained chart for Mixes 3 and 4. The aggregate gradation used in Mix 3 was developed using the natural blend as provided by the supplier. The aggregate gradation used in Mix 4 was developed using aggregate gradations manufactured in the laboratory. The CF and WF for these mixtures are located near the center of Zone II of the modified CF chart.

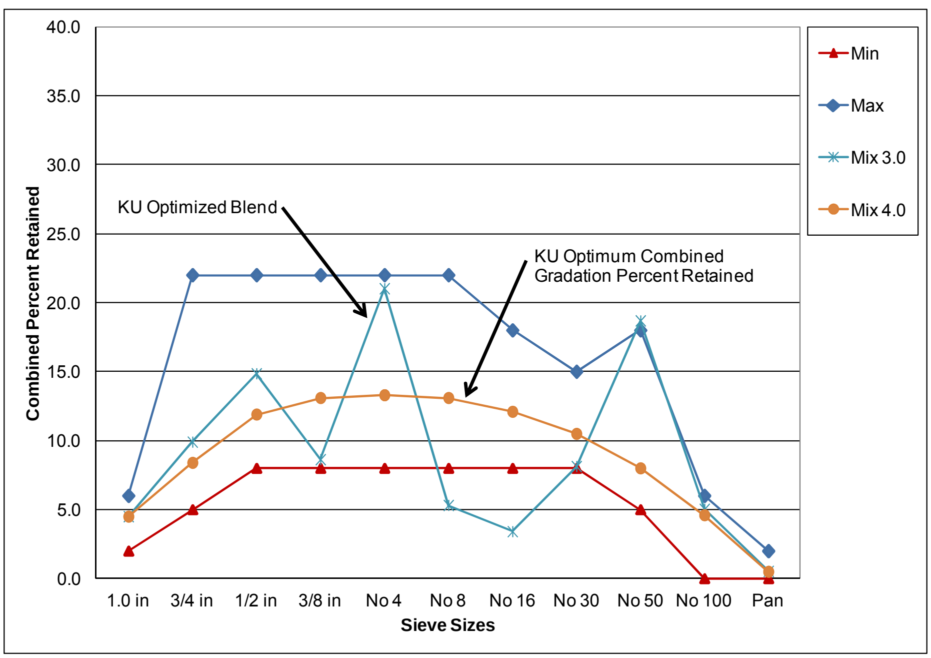

Figure 7 - Combined Percent Retained Chart - Mix 3 and 4

Mixes 5 Through 28

Guidelines for aggregates optimization were not used for Mixes 5 through 28 in order to generate mixtures used to evaluate all zones of the modified CF chart. The amount of aggregate particles retain on any individual sieve was adjusted as necessary to achieve the desired coarseness and adjusted workability numbers. Table 7 presents the combined percentage retained on each designated sieve for all thirty mixtures. Figures 9 through 14 present combined percent retained charts for all thirty mixtures. Only five mixtures are shown in each chart for clarity. Figure 15 presents the combined percent retained chart for all thirty mixtures.

Mix 29 - Influence of Combined Percent Retained Chart

Mix 29 was developed to explore the influence of the shape of the curve plotting the combined percent retained on individual sieves. Mix 29 is a repeat of Mix 1 except the combined individual percent retained curve has a different shape. Figure 8 presents the combined percent retained chart for Mixes 1 and 29.

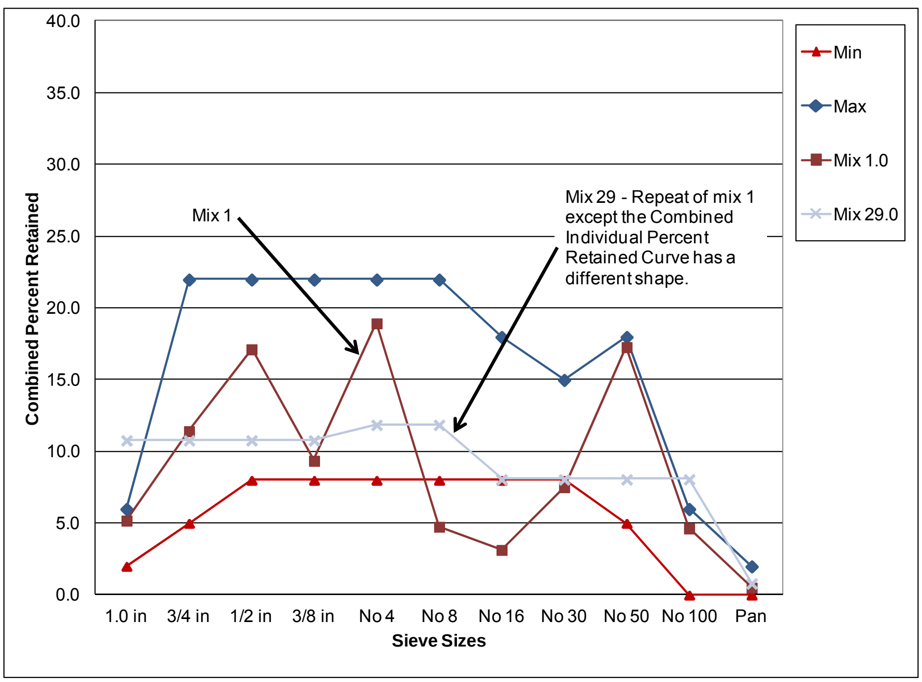

Figure 8 - Combined Percent Retained Chart - Mixes 1 and 29

Mix 30 - Influence of Adding 1 ½ Gallons of Water per Cubic Yard

Mix 30 was developed to determined the impact of adding 1 ½ gallons of water to a cubic yard to concrete. This water addition is allowed by MDOT for all classes of concrete except for Class BD (bridge deck) to adjust the slump to comply with the acceptable slump range. This water addition is found in section 804.02.12 “Concrete Bridges and Structures” in MDOT’s Specifications for Road and Bridge Construction. Mix 30 is a repeat of Mix 3 modified only by adding 1 ½ gallons of water per cubic yard.

Table 7 – Combined Percent Retained

Mix No.	Sieve Size										
	1 in.	**¾ in.**	**½ in.**	**3/8 in.**	**No 4**	**No 8**	**No 16**	**No 30**	**No 50**	**No 100**	**PAN**
1	5.20	11.43	17.14	9.37	18.95	4.77	3.15	7.52	17.29	4.65	0.52
2	5.69	9.76	11.39	12.20	12.48	12.48	11.34	9.86	7.40	4.93	2.47
3	4.50	9.90	14.85	8.63	21.02	5.31	3.41	8.13	18.69	5.03	0.53
4	4.50	8.40	11.90	13.10	13.30	13.10	12.10	10.50	8.00	4.60	0.50
5	3.24	7.12	10.68	8.99	39.53	6.95	2.20	5.25	12.08	3.25	0.72
6	2.43	5.34	8.01	6.18	25.11	6.85	4.40	10.50	24.15	6.50	0.53
7	8.17	14.00	16.33	17.50	7.00	7.00	9.45	8.22	6.16	4.11	2.05
8	6.29	10.78	12.58	13.48	5.39	5.39	14.52	12.63	9.47	6.32	3.16
9	5.27	11.57	17.36	10.39	26.96	5.08	2.20	5.25	12.08	3.25	0.62
10	4.05	8.90	13.35	7.75	18.94	5.52	3.96	9.45	21.74	5.85	0.50
11	8.06	13.81	16.11	17.27	4.88	4.88	11.03	9.59	7.19	4.79	2.40
12	2.43	5.34	8.01	7.08	32.89	7.19	3.52	8.40	19.32	5.20	0.62
13	5.68	12.48	18.72	10.24	15.73	2.15	3.37	8.05	18.52	4.98	0.08
14	5.06	11.13	16.69	9.13	15.84	2.16	3.86	9.20	21.16	5.70	0.09
15	3.62	7.95	11.92	6.52	26.40	3.60	3.86	9.20	21.16	5.70	0.09
16	5.91	12.98	19.47	10.65	18.48	2.52	2.89	6.90	15.87	4.27	0.07
17	4.22	9.27	13.91	7.60	30.80	4.20	2.89	6.90	15.87	4.27	0.07
18	3.72	8.18	12.27	6.71	30.03	4.10	3.37	8.05	18.52	4.98	0.08
19	6.33	13.91	20.86	11.41	19.80	2.70	2.41	5.75	13.23	3.56	0.05
20	4.52	9.93	14.90	8.15	32.99	4.51	2.41	5.75	13.23	3.56	0.05
21	5.79	12.71	19.07	10.43	10.56	1.44	3.86	9.20	21.16	5.70	0.09
22	2.89	6.36	9.54	5.21	31.68	4.32	3.86	9.20	21.16	5.70	0.09
23	3.38	7.42	11.13	6.08	36.95	5.05	2.89	6.90	15.87	4.27	0.07
24	4.34	9.54	14.30	7.82	21.12	2.88	3.86	9.20	21.16	5.70	0.09
25	5.06	11.13	16.69	9.13	24.64	3.36	2.89	6.90	15.87	4.27	0.07
26	7.05	15.50	23.24	12.71	5.72	0.78	3.37	8.05	18.52	4.98	0.08
27	3.98	8.74	13.11	7.17	19.36	2.64	4.34	10.35	23.81	6.41	0.10
28	7.59	16.69	25.03	13.69	6.16	0.84	2.89	6.90	15.87	4.27	0.07
29	10.79	10.79	10.79	10.79	11.87	11.87	8.07	8.07	8.07	8.07	0.81
30	4.50	9.90	14.85	8.63	21.02	5.31	3.41	8.13	18.69	5.03	0.53

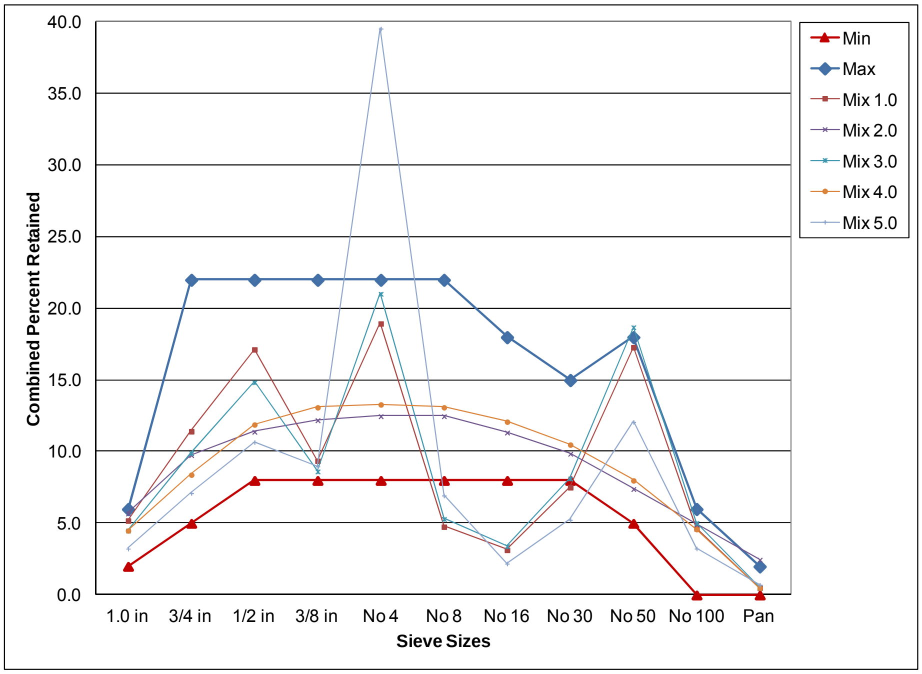

Figure 9 - Combined Percent Retained Chart - Mixes 1 Through 5

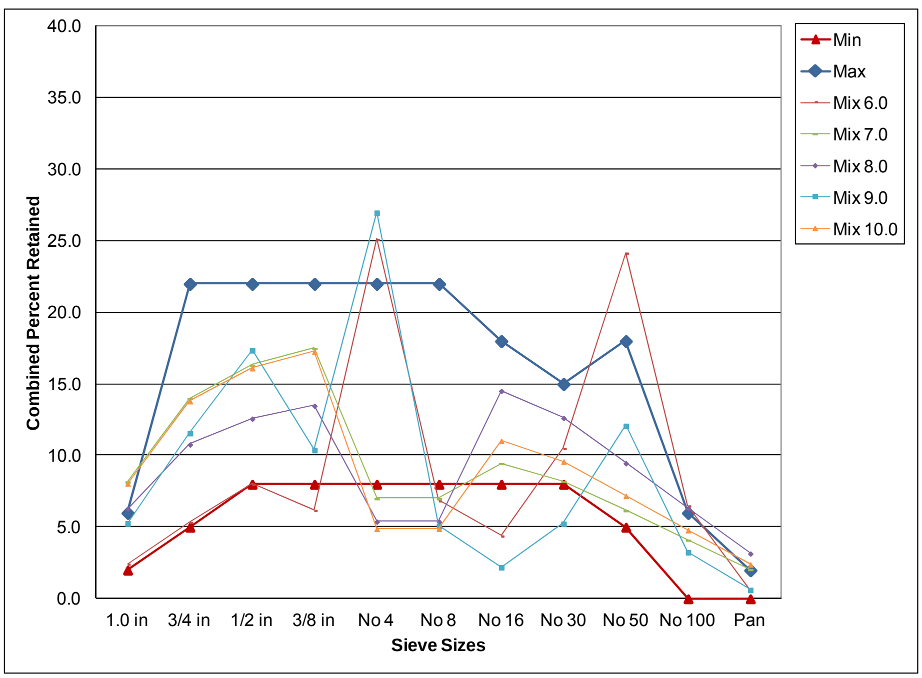

Figure 10 - Combined Percent Retained Chart - Mixes 6 Through 10

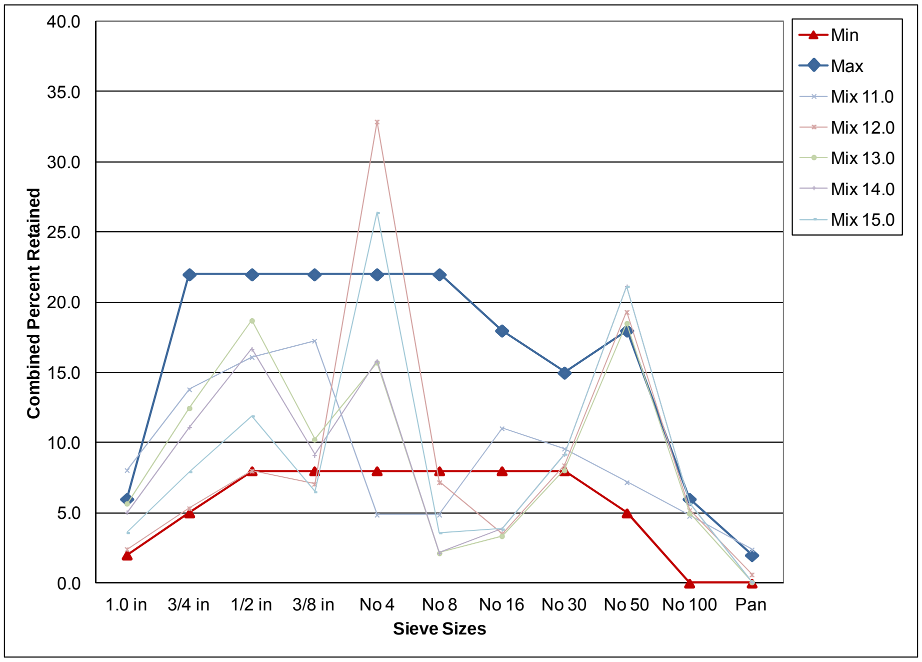

Figure 11 - Combined Percent Retained Chart - Mixes 11 Thru 15

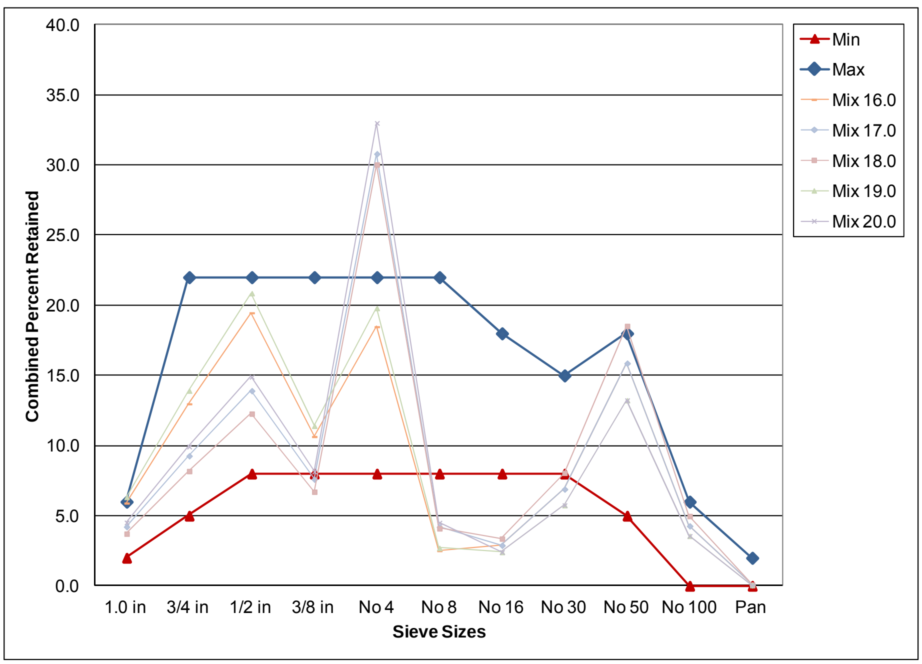

Figure 12 - Combined Percent Retained Chart - Mixes 16 Through 20

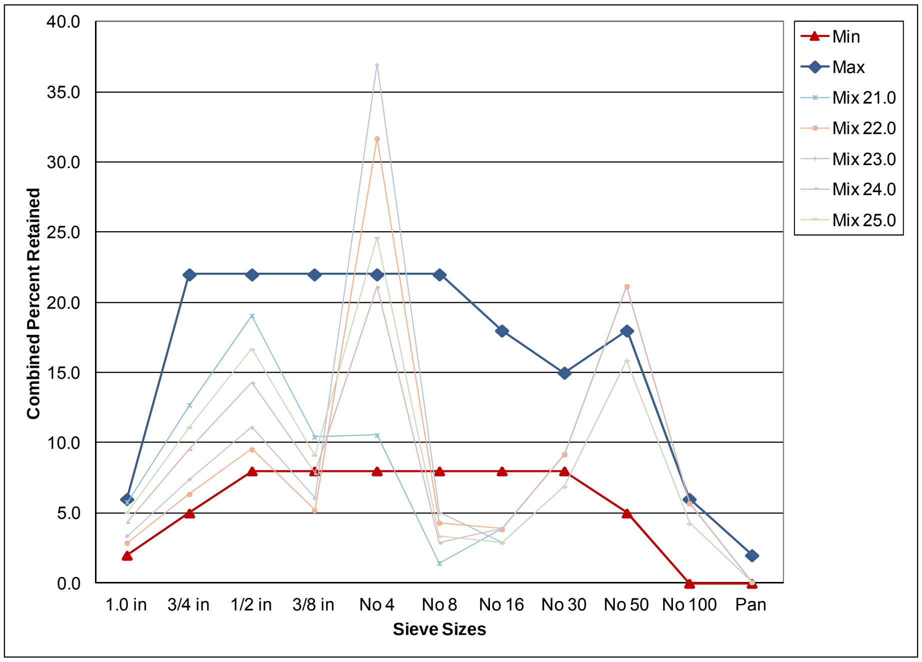

Figure 13 - Combined Percent Retained Chart - Mixes 21 Through 25

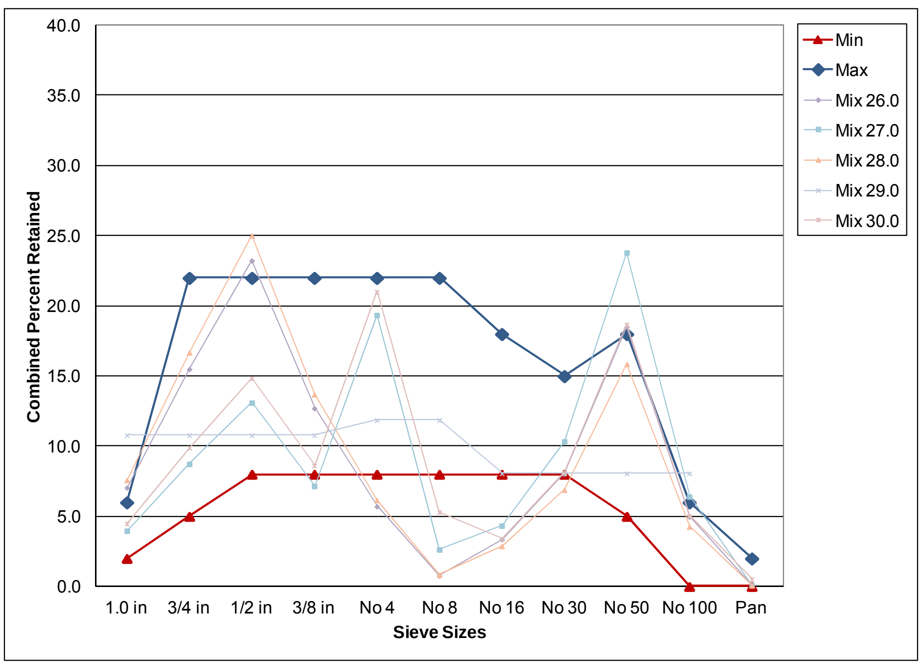

Figure 14 - Combined Percent Retained Chart - Mixes 26 Through 30

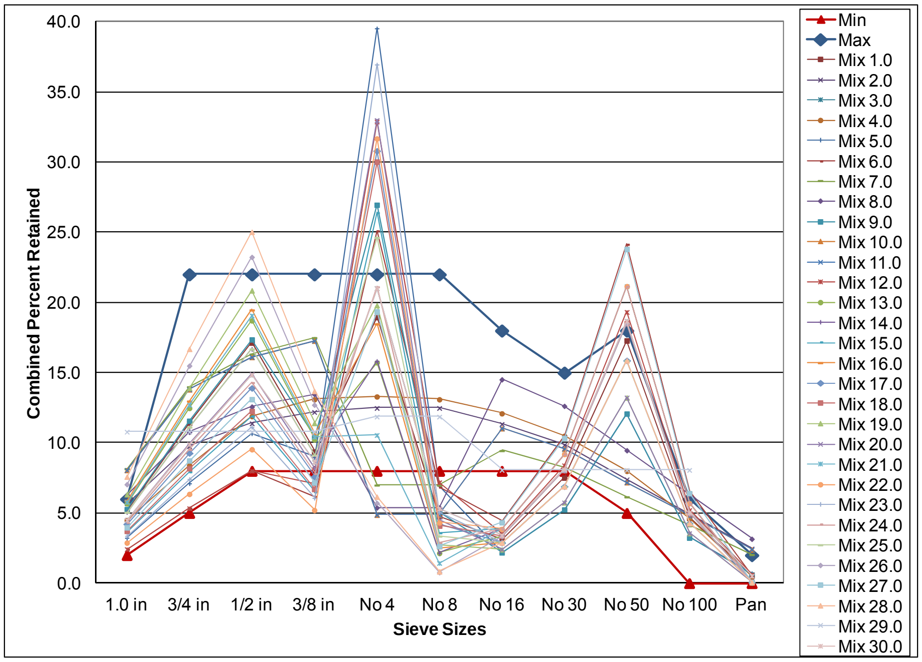

Figure 15 - Combined Percent Retained Chart - Mixes 1 Through 30

Chapter 4 - Laboratory Testing

Aggregate Testing

Typical testing was conducted on the aggregate samples for use in the concrete mixtures. These tests include; (1) AASHTO T 85 / ASTM C 127 “Specific Gravity and Absorption of Coarse Aggregate”, (2) AASHTO T 84 / ASTM C 128 “Specific Gravity and Absorption of Fine Aggregate”, and (3) AASHTO T 27 / ASTM C 136 “Sieve Analysis of Fine and Coarse Aggregates.” Additional tests were performed on the combination of sand and gravel to determine unit weight and voids in aggregates.

Unit Weight and Voids in Aggregates.

Dry-rodded unit weight and voids in aggregate were determined according to AASHTO T 19 / ASTM C 29 “Bulk Density (“Unit Weight”) and Voids in Aggregate” before each day’s mixing operations. All combined aggregate batches were tested regardless of the method used for blending. This testing was preformed after all individual size fractions of aggregates were weighed and ready to be introduced to the mixture. These aggregates were mixed together and split down to testing size according to AASHTO T 248 / ASTM C 702 “Reducing Sample of Aggregates to Testing Size” using method “B”, the quartering method. The aggregates were quartered on a hard, clean, level surface and opposing quarters retrieved for dry-rodded unit weight determination and void content calculations.

Gradation Check.

In several instances a sieve analysis was performed on the combined aggregate to compare with the desired gradation as a form of quality assurance. However, due to possibility of an error, a second sieve analysis check was performed only on the first few mixtures. Figure 16 presents an example of the desired combined grading for Mix 1 along with the sieve analysis check.

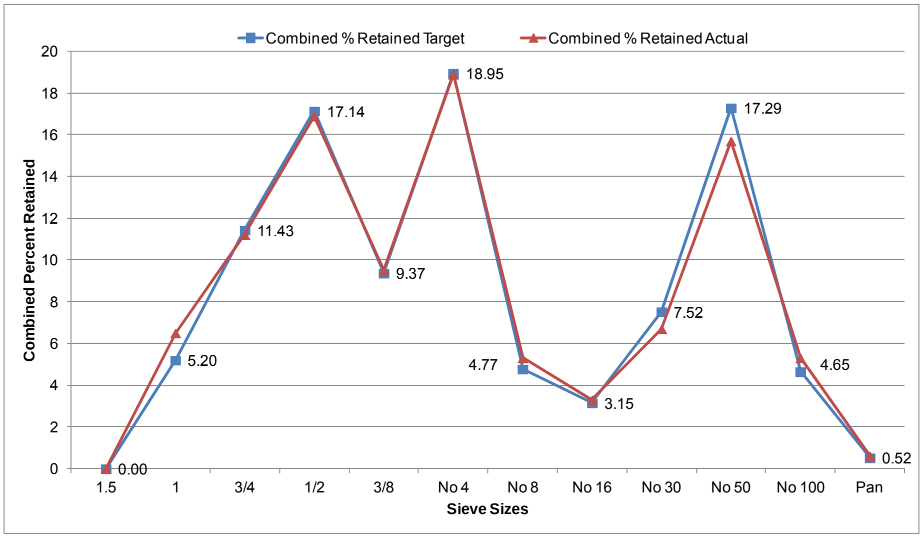

Figure 16 – Combined Aggregate Gradation Check - Mix 1

Mixing

Laboratory mixing was conducted in 1.25 cubic feet batch quantities using a revolving drum mixer in accordance with ASTM C 192 "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." Dry specific gravity and absorption values were used to adjust laboratory mixture designs based on aggregates in an oven-dry condition.

In accordance with ASTM C 192, the inside of the revolving-drum mixer received a thin layer of fresh concrete to prevent loss of mortar from the test batch. To add consistency to our process, a masonry brush was used to spread the fresh layer of concrete uniformly around the drum. The drum was inverted for a two minute waiting period to allow any free water to fall out before continuing. The mixer was then charged with the combined aggregates and approximately half of the mixing water. After minimal revolutions of the drum to mix up the aggregates and water, the mixer was stopped and covered to guard against moisture loss. A two minute rest period was introduced to our procedure to accommodate some degree of absorption by the oven-dry aggregates. After this two minute rest, the remaining materials were added to a mixer. A three minute mixing, three minute rest, two minute final mixing pattern was performed taking steps to guard against moisture loss during the rest period and segregation when discharging to a wheel barrow.

Plastic Properties

The fresh concrete was tested for density, yield, slump, air content and temperature. Fresh properties were recorded for each mixture. All testing was performed using ACI Certified Technicians according to the following applicable standards:

- **Density and Yield –** AASHTO T 121 / ASTM C 138 "Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete" (Figure 17)
- **Slump** – AASHTO T 119 / ASTM C 143 "Standard Test Method for Slump of Hydraulic-Cement Concrete" (Figure 18)
- **Air Content –** AASHTO T 196 / ASTM C 173 "Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method" (Figure 19)
- **Making and Curing Cylinder and Prisms –** AASHTO R 39 / ASTM C 192 "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory." (Figure 20)
- **Temperature** – ASTM C 1064 " Standard Test Method For Temperature of Freshly Mixed Hydraulic-Cement Concrete"

Figure 17 - Unit Weight Testing

Figure 18 - Slump Testing

Figure 19 - Air Content Testing

Figure 20 - Curing Specimens

Workability Index

Additional testing was performed on the fresh concrete in order to assign each mixture a number to represent workability. This number is referred to herein as workability index (WI). The author is not aware of any AASHTO or ASTM test method for determining workability so a procedure was developed by Burns Cooley Dennis, Inc. and used in this study to indicate how workable the mixtures may be for construction. This procedure used the slump test along with a vibrating table to simulate how the concrete would consolidate and move horizontally within forms for concrete construction. See Figure 21 and 22 for workability index testing.

In addition to standard slump testing, a standard slump test was performed on a vibrating table with the vibrating element turned off. The standard slump was measured as the pre-vibrated slump. The slump cone was then placed back onto the slumped concrete and allowed to move down the slumped concrete until a slight resistance from the concrete at the base would keep the slump cone from further downward movement without the use of force. The amplitude was set on the vibrating table at 10 percent for a vibration time period of 5 seconds. After vibration, the post vibrated slump was measured and a change in slump was calculated.

The post-vibrated horizontal spread of the base of the slumped concrete was also determined. Two measurements were taken at right angles and the two averaged to determine the average spread. Both change in slump and change in horizontal spread were used to determine a workability index (WI) in accordance with Equation 9.

$$WI = \sqrt{V^2 + H^2} \tag{9}$$

Where: WI = workability index

V = difference in pre-vibrated slump and post-vibrated slump

H = difference in pre-vibrated slump base spread (diameter of slump cone, 8 in.) and post-vibrated slump base spread

Figure 21 - Pre-Vibrated Slump and Base Spread

Figure 22 - Post-Vibrated Slump and Base Spread

Hardened Properties

Compressive Strength.

Compressive strength specimens were cast immediately following testing of all plastic properties. ACI certified technicians made the 4 in. x 8 in. specimens and consolidation was accomplished using a vibrating table. Upon completion of consolidation and strike-off finishing of the top surfaces, strength specimens were moved to a temperature controlled moisture room for curing. Specimens were tested by ACI certified strength technicians in accordance with AASHTO T 22 / ASTM C 39 "Standard Test method for Compressive Strength of Cylindrical Concrete Specimens." Eleven specimens were tested for each mixture as follows: 2 at 1 day, 2 at 7 days, 2 at 14 days, 3 at 28 days, and 2 at 56 days.

Length Change of Hardened Concrete.

Length change was measured for each mixture according for AASHTO T 160 / ASTM C 157 "Length Change of Hardened Hydraulic-Cement Mortar and Concrete" and AASHTO M 210 / ASTM C 490 "Standard Practice for use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete." Specimens were cast according to AASHTO R 39 / ASTM C 192 utilizing prisms of 4 in. square cross sections and approximately 11 ¼ in. long. Three specimens were cast for each mixture and consolidated with a vibrating table. Results shown in this report represent the average of the three specimens.

Sample Preparation.

Specimens were cast and consolidated utilizing an external vibratory table. Specimens were immediately placed in a moist curing room for a 24 hour initial curing period. Specimens were de-molded at an age of 23.5 ± 0.5 hours and were labeled with identifying information using a permanent marker. Specimens were then placed into a lime-saturated water curing bath maintained at 73 ± 1 degree Fahrenheit for 30 minutes before initial comparator reading.

Initial Testing.

Specimens were removed from the lime-saturated curing bath and towel dried, leaving only a small amount of free water. They were then placed in a comparator measuring to the nearest 0.0001 in. where initial measurements were taken and compared to a standard reference bar (Figure 23). Specimens were removed from the comparator and returned to the lime-saturated curing bath until they reached an age of 28 days from the time they were cast. At the end of the 28 day curing period the specimens received a second comparator reading (Figure 24).

Specimen Dry Storage and Testing.

Specimens were stored after the second reading in a temperature and humidity controlled environment of 50% ± 4% relative humidity and 73 ± 3 º F. Specimens were stacked on shelves with a clearance of at least 1 inch on all sides. Comparator readings were taken at 1, 28, 32, 35, 42, 56, 84, 140, 252, and 476 days after casting. Tables and figures in this report will indicate length change based on days in the temperature and humidity controlled room. These ages will be 4, 7, 14, 28, 56, 112, 224, and 448 days from the time the specimens were placed in the temperature and humidity controlled room, which is 28 days after casting.

Calculations.

Length change data was calculated and reported as a positive number if expansion occurred and a negative number (-) if shrinkage occurred. These data are reported to the nearest 0.0001% herein. The equation for calculating length change of specimens at any age as a percent of the initial comparator reading is as follows:

$$L = \frac{L_x - L_i}{G} * 100 \qquad (10)$$

Where:

L = change in length at X age, %

L_X = comparator reading of specimen at X age minus comparator reading of reference bar at X age; in inches

L_i = initial comparator reading of specimen minus comparator readings of reference bar at that same time; in inches

G = nominal gauge length; 10 inches. This nominal gage length is the length between inside ends of gauge studs cast into the prism specimens and is 10 ± 0.1 in.

Figure 23 - Comparator Reading of Standard Bar

Figure 24 - Comparator Reading of Concrete Specimen

Chapter 5 – Results

Water Demand and Cement Content

The slump test was used to evaluate water demand associated with combined aggregate gradations. All mixtures were compared to control mixtures having coarseness factors and adjusted workability factors plotting within MDOT's elliptical limits of the modified CF chart. As measured slump increased or decreased as a result of changes in combined aggregate gradations, water and cement content were adjusted in order to maintain a w/c ratio of 0.45 and a slump of 2 ½ in. to 3 ½ in.. Table 8 presents a summary of cement and water contents of all mixtures. Cement contents ranged from 484.1 pounds per cubic yard (PCY) to 578.1 PCY. Water content ranged from 217.85 PCY to 260.15 PCY. Figure 25 presents a modified CF chart with Mixes 1 through 30 plotted on the chart showing cement contents associated with each mixture.

Table 8 - Cement and Water Content

Cement Content (lbs/yd^3)	Water Content (lbs/yd^3)	Mixes
484.10	217.85	7, 11, 13, 16, 17, 19, 20, 25, 26, 28
512.30	230.54	23
526.40	236.88	1, 2, 3, 4, 5, 9, 12, 14, 15, 18, 21, 22, 24, 29
526.40	245.21	30
564.00	253.80	10
578.10	260.15	6, 8, 27

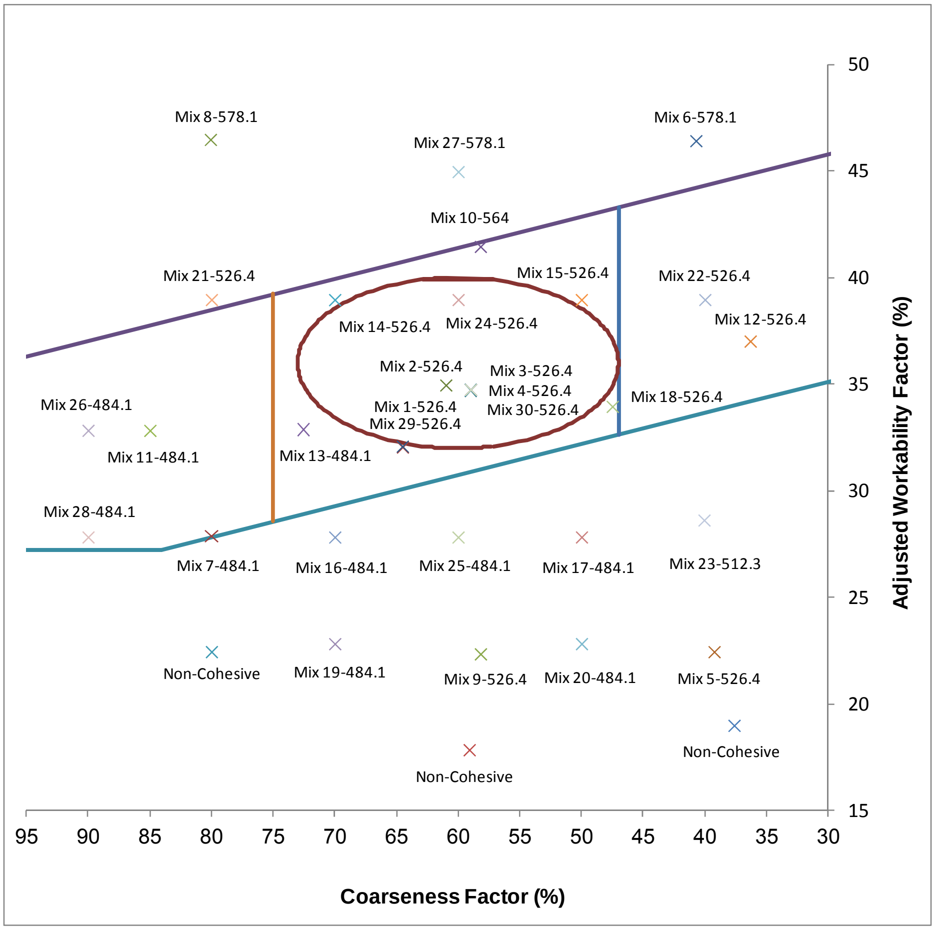

Figure 25 - Modified Coarseness Factor Chart (Cement Content)

Unit Weight and Voids in Aggregates

Dry-rodded unit weight and void content of the combined aggregate gradation used in each mixture are presented in Table 9. Dry-rodded unit weight ranged from a low of 118.5 pounds per cubic feet (pcf) (Mix 9) to a high of 126.5 pcf (Mix 8). Void content ranged from 19.8 percent (Mix 26) to 24.4 percent (Mix 5). Percent voids in aggregates versus unit weight data are presented in Figure 26.

Table 9 – Dry-Rodded Unit Weight and Voids in Aggregates

Mix Number	Dry-Rodded Unit Weight (lbs/ft^3)	Void Content (%)
1	125.5	20.3
2	123.8	21.5
3	124.6	21.1
4	121.0	23.3
5	118.6	24.4
6	123.6	22.3
7	123.2	21.6
8	126.5	20.2
9	118.5	24.3
10	123.1	22.3
11	125.0	20.7
12	122.2	22.7
13	124.5	21.0
14	125.7	20.5
15	124.7	20.9
16	124.9	20.5
17	123.6	21.4
18	123.8	21.5
19	120.5	23.1
20	121.1	22.8
21	125.9	20.3
22	123.1	22.2
23	123.7	21.4
24	125.5	20.6
25	122.4	22.2
26	126.4	19.8
27	124.9	21.2
28	125.7	20.0
29	125.4	20.3
30	124.8	21.0

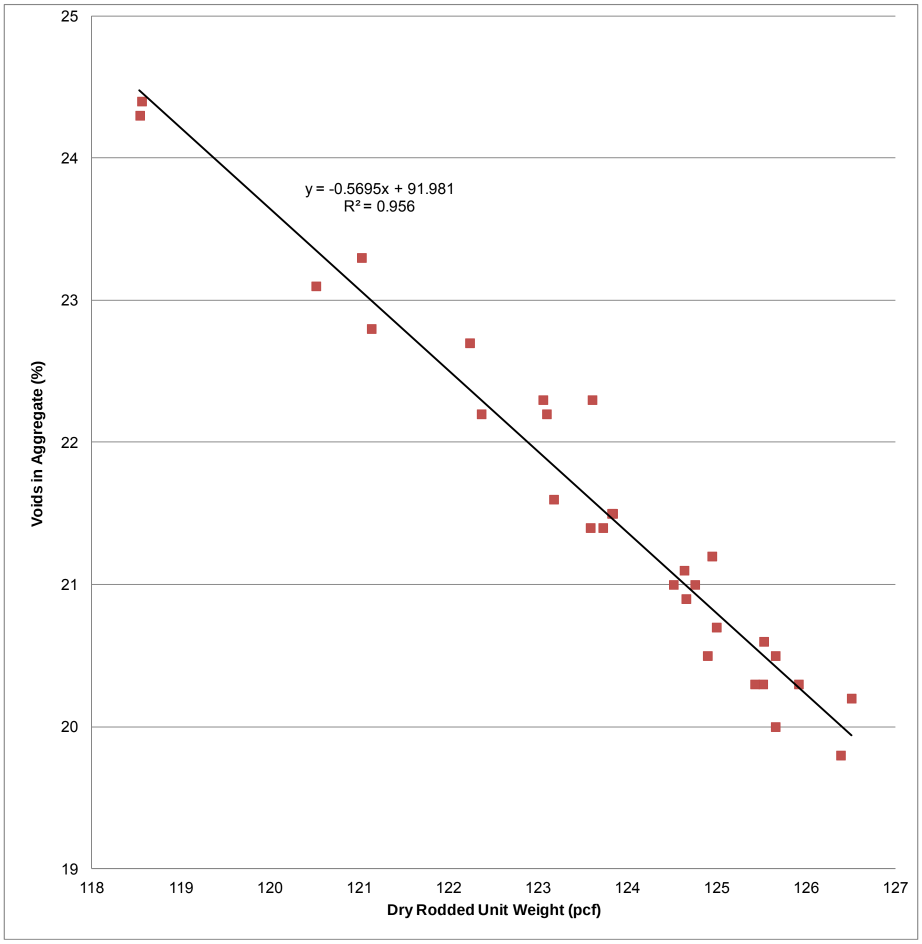

Figure 26 - Voids in Aggregate vs Dry-Rodded Unit Weight

Plastic Properties

Plastic properties of each concrete mixture are presented in Table 10. Slump ranged from 2 ½ in. to 3 ½ in. for all mixtures except for Mixes 29 and 30. Mix 29 is a repeat Mix 1 except for the shape of the combined percent retained chart. Mix 30 is a repeat of Mix 3 except 1 ½ gallons of water per cubic yard were added to Mix 30. Entrapped air ranged from 1.5 percent (Mix 9) to 5.75 percent (Mix 6). Unit weight ranged from 143.6 pcf (Mix 6) to 148.0 pcf (Mix 19).

Table 10 - Plastic Properties

Mix No.	Slump (in.)	Air (%)	Temp (ºF)	Unit Wt (lbs/ft^3)
1	3.25	2.75	80.1	146.20
2	3.25	3.00	74.8	145.20
3	3.25	3.00	74.5	145.60
4	3.50	3.25	73.2	144.60
5	3.00	1.75	73.2	146.80
6	3.00	5.75	72.9	143.60
7	2.50	2.00	73.5	147.80
8	2.75	3.25	70.4	145.40
9	3.50	1.50	73.5	147.20
10	3.25	3.75	75.4	144.40
11	2.75	2.50	71.0	146.60
12	2.50	3.00	71.0	145.80
13	2.50	3.25	73.1	146.80
14	2.50	4.25	72.9	144.68
15	2.75	4.00	71.5	144.08
16	3.25	2.50	71.5	146.80
17	3.00	3.00	69.5	147.00
18	3.50	3.00	69.5	145.80
19	3.00	1.75	69.5	148.00
20	2.75	2.25	70.5	147.40
21	3.00	3.50	70.5	145.80
22	2.75	4.00	71.0	144.20
23	3.00	2.50	75.5	146.20
24	2.50	4.00	75.0	144.80
25	2.50	2.25	73.0	146.40
26	2.75	3.00	73.0	145.80
27	3.00	3.50	75.5	144.20
28	3.25	2.25	74.0	147.60
29	4.50	2.50	70.0	146.40
30	5.50	2.75	70.0	146.40

Workability Index

The ease of which concrete can be placed, consolidated, and finished is important to the overall quality of concrete construction. This study used a modified slump test to get an indication of the workability of each concrete mixture. Table 11 presents measurements of the pre-vibrated slump, post-vibrated slump, spread, and calculated Workability Index (WI). WI ranged from 3.8 in. (Mix 7) to 9.7 in. (Mix 10).

Table 11 - Workability Index

Mix Number	Pre-Vibrate Slump (in.)	Post-Vibrated Sump (in.)	Change In Slump (in.)	Spread 1 (in.)	Spread 2 (in.)	Average Spread (in.)	Change In Spread (in.)	Workability Index (WI)
1	3.75	6.25	2.5	14.5	13.5	14.0	6.0	6.5
2	3.75	6.25	2.5	14.5	13.5	14.0	6.0	6.5
3	2.25	4.75	2.5	14.0	10.75	12.38	4.38	5.0
4	2.0	5.0	3.0	13.0	12.75	12.88	4.88	5.7
5	4.0	5.75	1.75	12.0	12.25	12.13	4.13	4.5
6	2.75	6.5	3.75	15.25	15.0	15.13	7.13	8.1
7	2.25	4.5	2.25	11.0	11.0	11.00	3.0	3.8
8	2.25	4.75	2.5	12.25	10.5	11.38	3.38	4.2
9	3.0	6.5	3.5	13.0	13.25	13.13	5.13	6.2
10	3.25	8.75	5.5	17.0	15.0	16.00	8.0	9.7
11	2.25	5.5	3.25	12.5	12.25	12.38	4.38	5.5
12	1.75	5.5	3.75	13.25	13.0	13.13	5.13	6.4
13	2.0	5.5	3.5	12.5	13.0	12.75	4.75	5.9
14	2.0	5.0	3.0	10.75	10.125	10.44	2.44	3.9
15	2.50	8.25	5.75	14.875	13.625	14.25	6.25	8.5
16	2.0	5.0	3.0	12.5	12.0	12.25	4.25	5.2
17	2.25	6.5	4.25	13.75	12.25	13.0	5.0	6.6
18	2.50	7.25	4.75	15.25	14.5	14.88	6.88	8.4
19	3.25	7.0	3.75	13.5	13.5	13.50	5.50	6.7
20	2.0	4.75	2.75	11.75	11.00	11.38	3.38	4.4
21	2.75	7.5	4.75	13.375	14.375	13.88	5.88	7.6
22	2.25	7.50	5.25	14.25	13.875	14.06	6.06	8.0
23	2.75	6.5	3.75	14.25	14.25	14.25	6.25	7.3
24	1.75	6.25	4.5	13.0	14.25	13.63	5.63	7.2
25	1.75	4.50	2.75	12.0	11.50	11.75	3.75	4.7
26	2.00	5.50	3.5	13.0	13.25	13.13	5.13	6.2
27	2.0	7.5	5.5	14.5	14.5	14.50	6.50	8.5
28	4.0	7.0	3.0	12.25	12.25	12.25	4.25	5.2
29	4.0	8.75	4.75	15.25	15.50	15.38	7.38	8.8
30	4.25	7.75	3.5	15.50	15.50	15.50	7.50	8.3

Compressive Strength

Results from testing eleven compressive strength specimens per mixture are given in this section. These specimens were tested as follows; 2 at 1 day, 2 at 7 days, 2 at 14 days, 3 at 28 days, and 2 at 56 days. Results shown in this report are calculated as the average of specimens tested for each age. Compressive strength results of each specimen were rounded to the nearest 10 pounds per square inch (psi). These individual tests at each test age were averaged and rounded to the nearest 1 psi for reporting. Each mixture has an average compressive strength that exceeds MDOT's specified 28 day strength requirement of 4,000 psi for bridge deck concrete.

Average 28 day compressive strengths ranged from 4,433 psi (Mix 15) to 6,093 psi (Mix 20). Table 12 presents the average compressive strengths and rankings for Mixes 1 through 30. A ranking of 1 indicates the highest compressive strength and a ranking of 30 indicates the lowest compressive strength.

Percent Length Change

Testing was performed on all mixtures to determine unrestrained length change. The ages given in the tables and figures are not from time of casting, but from the time specimens were placed in the controlled room at a temperature of 73º ± 3º F and 50 ± 4 percent humidity. Data indicate that ultimate shrinkage occurred at 448 days of storage in the temperature and humidity controlled room. Ultimate shrinkage ranged from a low of (-) 0.0203 percent (Mix 20) to a high of (-) 0.0450 percent (Mix 6). Average percent length change and rankings for Mixes 1 through 30 are shown in Table 13. A ranking of 1 represents the lowest average 448 day shrinkage and a ranking of 30 represents the highest 448 day shrinkage.

A summary of mixture parameters, plastic properties, and test results is presented in Table 14.

Table 12 – Average Compressive Strength

Mix No.	28 Day Avg. (psi)	28 Day Rank	56 Day Avg. (psi)	56 Day Rank
1	5,120	20	5,345	27
2	5,530	10	6,130	6
3	5,393	13	5,960	10
4	5,493	11	6,010	8
5	5,533	9	5,915	12
6	5,170	18	5,460	25
7	5,540	8	5,740	14
8	5,897	4	6,115	7
9	6,027	2	6,275	4
10	5,613	6	5,580	21
11	5,360	14	5,985	9
12	5,247	16	5,530	23
13	4,883	24	5,305	28
14	4,813	25	5,055	29
15	4,433	30	5,565	22
16	4,960	22	5,405	26
17	5,170	18	5,640	20
18	4,900	23	5,470	24
19	5,603	7	6,145	5
20	6,093	1	6,575	3
21	5,417	12	5,650	18
22	5,110	21	4,830	30
23	5,667	5	6,735	1
24	4,810	26	5,695	16
25	5,203	17	5,940	11
26	4,630	28	5,650	18
27	4,490	29	5,660	17
28	5,917	3	6,655	2
29	5,330	15	5,720	15
30	4,677	27	5,760	13

Table 13 – Average Percent Length Change and Ranking

Mix No.	28 Day Avg. (%)	28 Day Rank	448 Day Avg. (%)	448 Day Rank
1	-0.0120	13	-0.0275	8
2	-0.0097	5	-0.0347	20
3	-0.0143	16	-0.0350	22
4	-0.0183	26	-0.0390	26
5	-0.0203	29	-0.0400	27
6	-0.0190	28	-0.0450	30
7	-0.0100	6	-0.0255	4
8	-0.0180	25	-0.0373	25
9	-0.0147	19	-0.0333	18
10	-0.0145	18	-0.0365	24
11	-0.0117	12	-0.0307	12
12	-0.0185	27	-0.0400	28
13	-0.0170	24	-0.0347	21
14	-0.0150	20	-0.0360	23
15	-0.0120	14	-0.0327	15
16	-0.0083	2	-0.0230	2
17	-0.0107	8	-0.0283	9
18	-0.0107	9	-0.0307	12
19	-0.0093	3	-0.0243	3
20	-0.0060	1	-0.0203	1
21	-0.0097	4	-0.0260	5
22	-0.0110	10	-0.0310	14
23	-0.0163	23	-0.0330	16
24	-0.0100	6	-0.0290	10
25	-0.0123	15	-0.0303	11
26	-0.0113	11	-0.0273	7
27	-0.0217	30	-0.0427	29
28	-0.0143	17	-0.0270	6
29	-0.0155	21	-0.0345	19
30	-0.0157	22	-0.0333	17

Table 14 - Mixture Parameters, Plastic Properties, Test Results

Mix Number	Combined Aggregate Properties					Paste				Plastic Properties				Test Results	
	CF	WF	AWF	DRUW	Voids	w/c	Cement (lbs)	Water (lbs)	Paste Volume (%)	Slump (in.)	Air (%)	Temperate (º F)	Unit Weight (pcf)	28 Day (psi)	448 Day Shrinkage (%)
1	64.5	33.1	32.1	125.5	20.3	0.45	526.40	236.88	24.01	3.25	2.75	80.1	146.2	5,120	-0.0275
2	61.0	36.0	35.0	123.8	21.5	0.45	526.40	236.88	23.82	3.25	3.00	74.8	145.2	5,530	-0.0347
3	59.0	35.8	34.8	124.6	21.1	0.45	526.40	236.88	23.87	3.25	3.00	74.5	145.6	5,393	-0.0350
4	58.9	35.7	34.7	121.0	23.3	0.45	526.40	236.88	23.71	3.50	3.25	73.2	144.6	5,493	-0.0390
5	39.2	23.5	22.5	118.6	24.4	0.45	526.40	236.88	24.15	3.00	1.75	73.2	146.8	5,533	-0.0400
6	40.7	46.1	46.5	123.6	22.3	0.45	578.10	260.15	25.94	3.00	5.75	72.9	143.6	5,170	-0.0450
7	80.0	30.0	27.9	123.2	21.6	0.45	484.10	217.85	22.22	2.50	2.00	73.5	147.8	5,540	-0.0255
8	80.0	46.1	46.5	126.5	20.2	0.45	578.10	260.15	26.31	2.75	3.25	70.4	145.4	5,897	-0.0373
9	58.2	23.4	22.4	118.5	24.3	0.45	526.40	236.88	24.28	3.50	1.50	73.5	147.2	6,027	-0.0333
10	58.2	41.5	41.5	123.1	22.3	0.45	564.00	253.80	25.46	3.25	3.75	75.4	144.4	5,613	-0.0365
11	85.0	35.0	32.9	125.0	20.7	0.45	484.10	217.85	22.01	2.75	2.50	71.0	146.6	5,360	-0.0307
12	36.3	37.1	36.1	122.2	22.7	0.45	526.40	236.88	23.88	2.50	3.00	71.0	145.8	5,247	-0.0400
13	72.5	35.0	32.9	124.5	21.0	0.45	484.10	217.85	22.02	2.50	3.25	73.1	146.8	4,883	-0.0347
14	70.0	40.0	39.0	125.7	20.5	0.45	526.40	236.88	23.69	2.50	4.25	72.9	144.7	4,813	-0.0360
15	50.0	40.0	39.0	124.7	20.9	0.45	526.40	236.88	23.58	2.75	4.00	71.5	144.1	4,433	-0.0327
16	70.0	30.0	27.9	124.9	20.5	0.45	484.10	217.85	22.06	3.25	2.50	71.5	146.8	4,960	-0.0230
17	50.0	30.0	27.9	123.6	21.4	0.45	484.10	217.85	22.08	3.00	3.00	69.5	147.0	5,170	-0.0283
18	47.5	35.0	34.0	123.8	21.5	0.45	526.40	236.88	23.90	3.50	3.00	69.5	145.8	4,900	-0.0307
19	70.0	25.0	22.9	120.5	23.1	0.45	484.10	217.85	22.27	3.00	1.75	69.5	148.0	5,603	-0.0243
20	50.0	25.0	22.9	121.1	22.8	0.45	484.10	217.85	22.17	2.75	2.25	70.5	147.4	6,093	-0.0203
21	80.0	40.0	39.0	125.9	20.3	0.45	526.40	236.88	23.79	3.00	3.50	70.5	145.8	5,417	-0.0260
22	40.0	40.0	39.0	123.1	22.2	0.45	526.40	236.88	23.60	2.75	4.00	71.0	144.2	5,110	-0.0310
23	40.0	30.0	28.6	123.7	21.4	0.45	512.30	230.54	23.32	3.00	2.50	75.5	146.2	5,667	-0.0330
24	60.0	40.0	39.0	125.5	20.6	0.45	526.40	236.88	23.70	2.50	4.00	75.0	144.8	4,810	-0.0290
25	60.0	30.0	27.9	122.4	22.2	0.45	484.10	217.85	22.00	2.50	2.25	73.0	146.4	5,203	-0.0303
26	90.0	35.0	32.9	126.4	19.8	0.45	484.10	217.85	21.88	2.75	3.00	73.0	145.8	4,630	-0.0273
27	60.0	45.0	45.4	124.9	21.2	0.45	578.10	260.15	26.07	3.00	3.50	75.5	144.2	4,490	-0.0427
28	90.0	30.0	27.9	125.7	20.0	0.45	484.10	217.85	22.19	3.25	2.25	74.0	147.6	5,917	-0.0270
29	64.5	33.1	32.1	125.4	20.3	0.45	526.40	236.88	24.05	4.50	2.50	70.0	146.4	5,330	-0.0345
30	59.0	35.8	34.8	124.8	21.0	0.47	526.40	245.21	24.66	5.50	2.75	70.0	146.4	4,677	-0.0333

Chapter 6 – Discussion of Results

Water Demand and Cement Content

Data generated in this study confirm that combined aggregate gradations of mixtures do influence water demand. Mixtures with coarseness factors and adjusted workability factors that plot outside of MDOT's elliptical limits on the modified CF chart can either increase or decrease water demand. Data supports that slump increases as CF increases and AWF decreases compared to similar mixtures that plot within MDOT's elliptical limits on the modified CF chart. Additionally, the slump decreases as CF decreases and AWF increases. Therefore, if the goal of the mixture designer is to have the least amount of water and cement to produce a given slump, CF and AWF should plot in certain areas of Zones "I", "V", and in the "Trend Bar." These areas are noted in Figure 25 by mixes with cement contents that are less than 526.4 PCY. The designer should also avoid Zone "IV" because of the excess fines which cause the water demand to increase.

Dry-Rodded Unit Weight and Voids in Aggregate

The amount of concrete shrinkage is influenced by the amount of cementitious paste in concrete mixtures. As paste content increases, concrete shrinkage also increases. One way to reduce the amount of cement paste in a given volume of concrete is to reduce the void space inherent between aggregate particles. The concrete mixture designer is then challenged to develop blends of various coarse and fine aggregate sizes to fill in as many voids between the aggregates as possible with various aggregate particle sizes. Understanding the range of voids in aggregates that can be expected when using Mississippi sand and gravel will assist in determining the optimum grading.

This research included the determination of voids in aggregate calculated from dry-rodded unit weights of twenty-nine unique aggregate gradations. The minimum void content was 19.8 percent and was produced from the combined aggregate gradation used in Mix 26. The maximum void content was 24.4 percent and was produced in Mix 5. Figure 27 presents a plot of the dry-rodded unit weight of aggregates for each mixture on the modified CF chart. Figure 28 presents a plot of the calculated void content for each mixture on the modified CF chart.

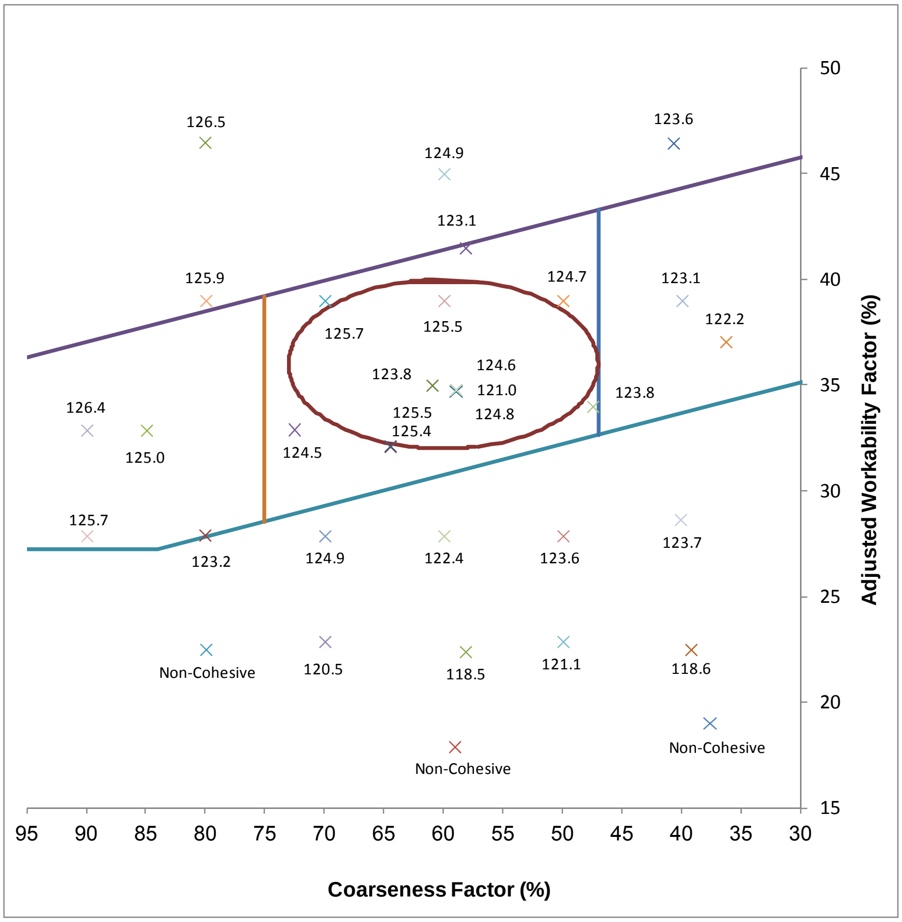

Figure 27 - Modified Coarseness Factor Chart (Dry Rodded Unit Weight)

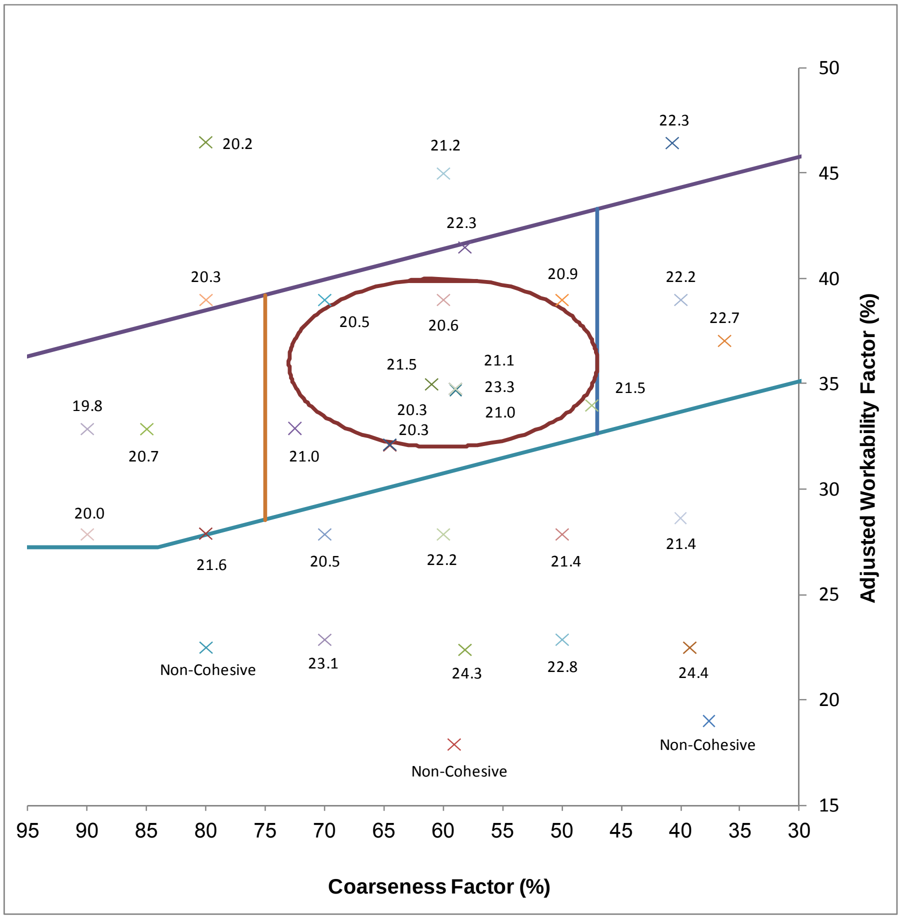

Figure 28 - Modified Coarseness Factor Chart (% Voids in Aggregate)

In order to compare void content in aggregates between the mixtures in this study, void content categories had to be developed. Based on the author's opinion, voids in Mississippi aggregates can be divided into three categories including; low, moderate, and high. See Table 15 for categories for voids in aggregate.

Table 15 – Categories for Voids in Aggregate

Voids in Aggregate	Category
% Voids < 21	Low
21 ≤ % Voids ≤ 22	Moderate
% Voids ≥ 22	High

Similar unit weight and void content tests have been conducted by the National Ready Mixed Concrete Association (NRMCA) on crushed limestone aggregates. Void contents in the NRMCA study ranged from 21.6 percent to 26.7 percent (12). When comparing voids contents of crushed limestone of the NRMCA study and void contents determined on Mississippi gravel in this study, it appears that Mississippi gravel aggregates may create less void content in concrete than crushed limestone aggregates.

The combined percent retained charts for aggregate gradations that produced the minimum and maximum void space are presented in Figure 29. Mix 5 (highest voids) contained an excess of No. 4 size particles and a deficiency of material retained on the No 8, No 16, and No 30 sieves when compared to MDOT's upper and lower limits for combined percent retained on individual sieves for Class BD concrete. Mix 26 (lowest voids) had a slight excess of 1 in. and ½ in. particle sizes and a deficiency of material retained on No 4, No 8 and No 16 sieves when compared to MDOT's limits for Class BD concrete. Aggregate gradations that provided the lowest percent voids produced in this study could not be used as MDOT Class BD concrete because they do not meet criteria established for combined percent retained on individual sieves for Class BD concrete.

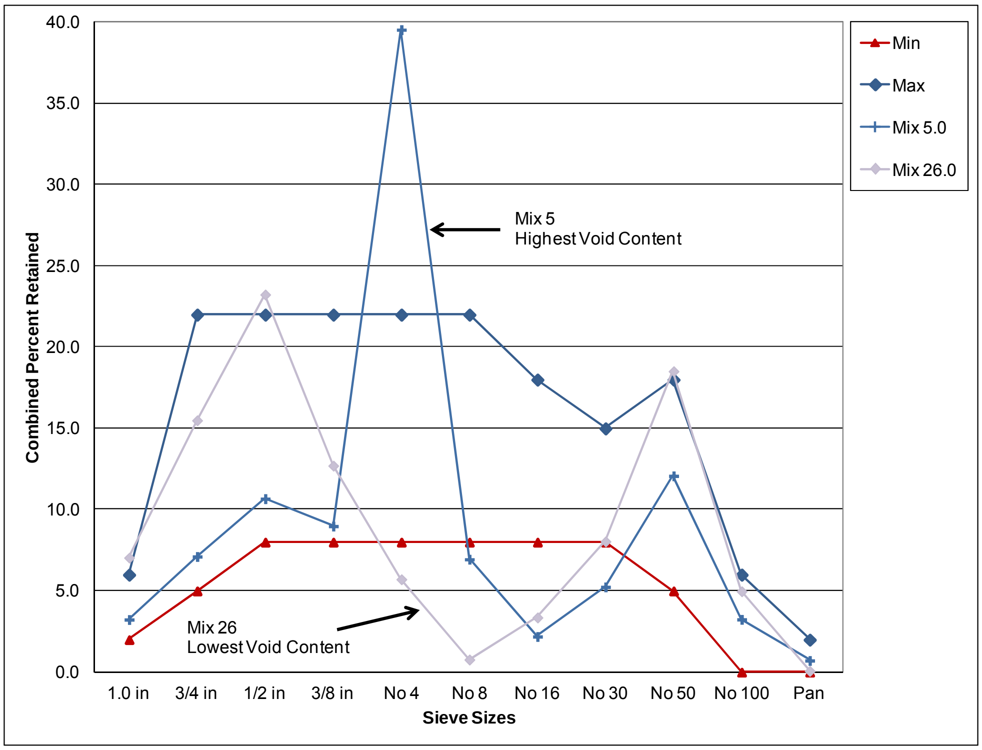

Figure 29 - Combined Percent Retained Chart - Mixes 5 and 26

Figures 30 through 32 present the combined percent retained charts for mixtures with aggregate gradations producing low, moderate, and high percent voids, respectfully. The "hay stack" gradation of Mix 4 met all requirements for combined percent retained on individual sieves found in ACI 302.1R section 5.4.3 and MDOT's specifications for Class BD concrete. The hay stack gradation of Mix 2 met all of these requirements for combined percent retained on individual sieves except for exceeding the maximum of 2 percent retained in the pan required for Class BD. The excess of material in the pan for Mix 2 was 0.47 percent. Even though combined aggregate gradations of Mixes 2 and 4 met these requirements for combined percent retained on individual sieves, the "hay stack" gradations provided moderate to high percent void contents in aggregate. The void contents of Mixes 2 and 4 are 21.5 percent and 23.3 percent, respectively.

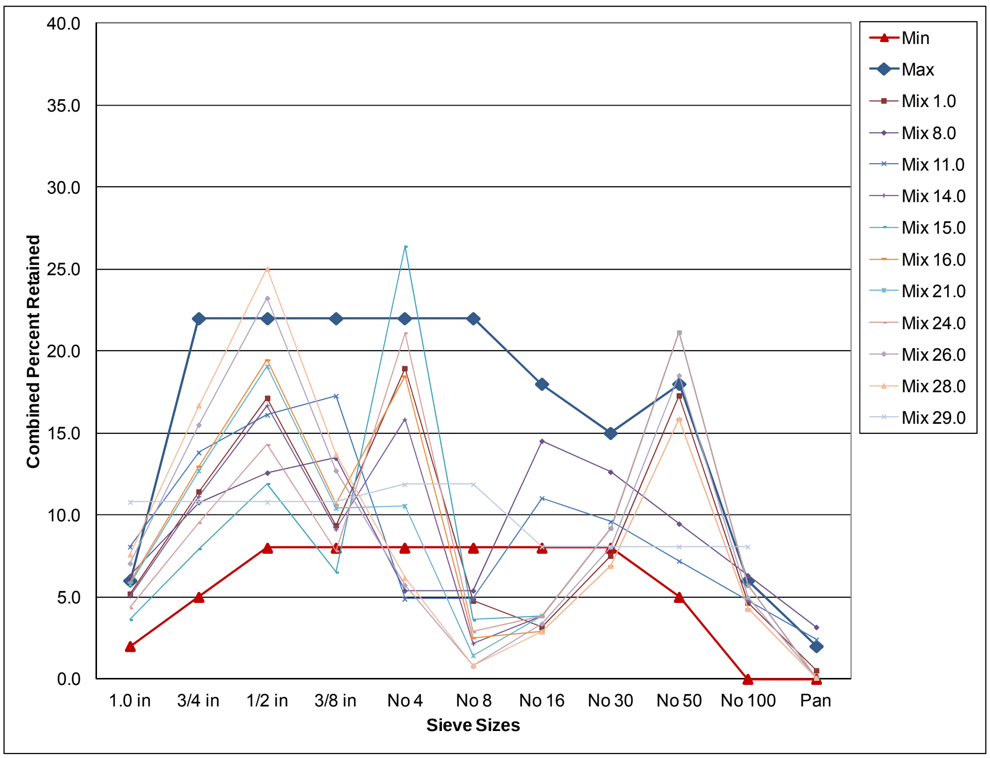

Figure 30 - Combined Percent Retained Chart with Percent Voids < 21%

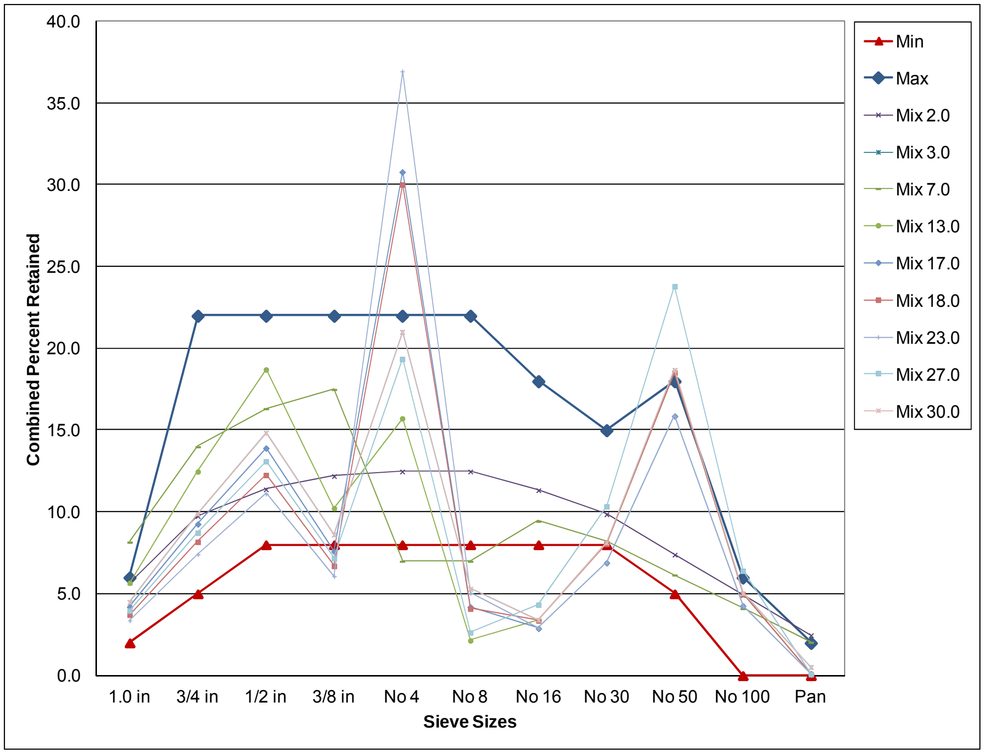

Figure 31 - Combined Percent Retained Chart with Percent Voids Between 21% and 22%

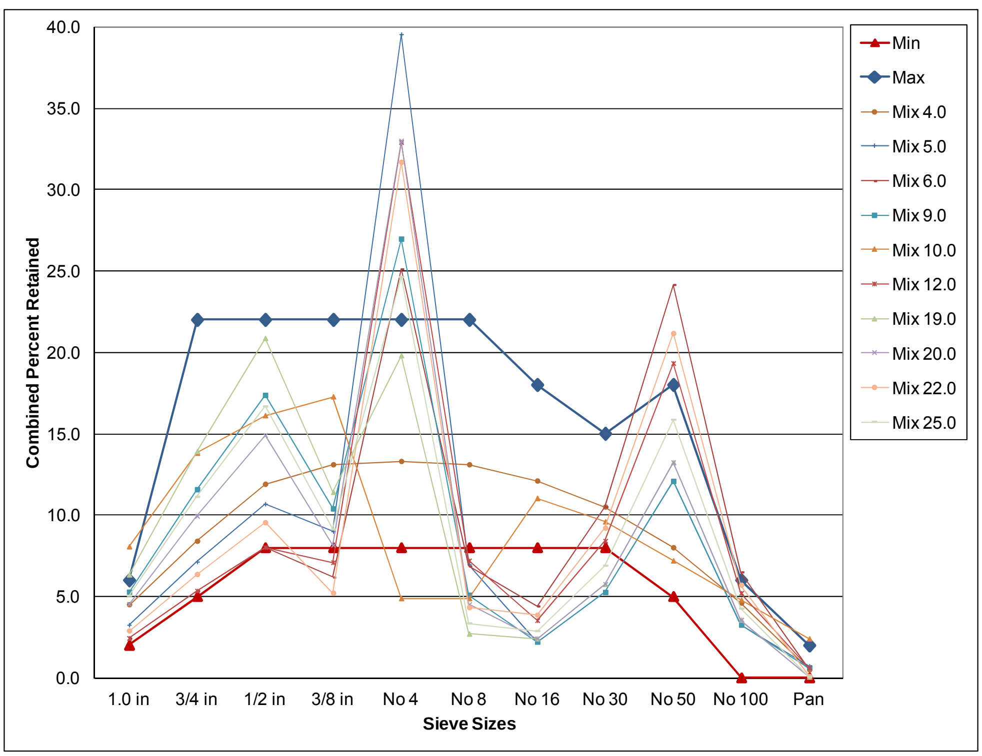

Figure 32 - Combined Percent Retained Chart with Percent Voids Greater Than 22%

Figures 33 and 34 present voids in aggregates verses coarseness factor and adjusted workability factor, respectfully. Data presented in Figure 33 show that voids in aggregates decrease as coarseness factor increases. Figure 34 also shows a decrease in voids in aggregates as adjusted workability factor increases. However, this trend reverses at a workability factor of approximately 37.5 and voids in aggregates begin to increase as adjusted workability factors exceed 37.5.

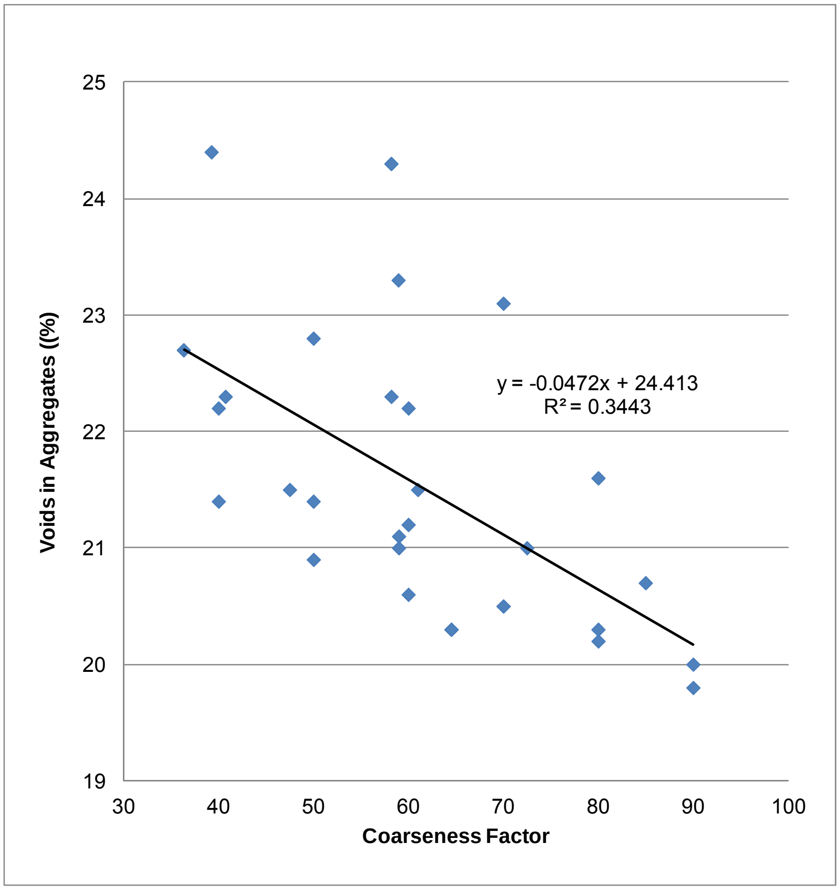

Figure 33 - Influence of Coarseness Factor on Voids in Aggregate

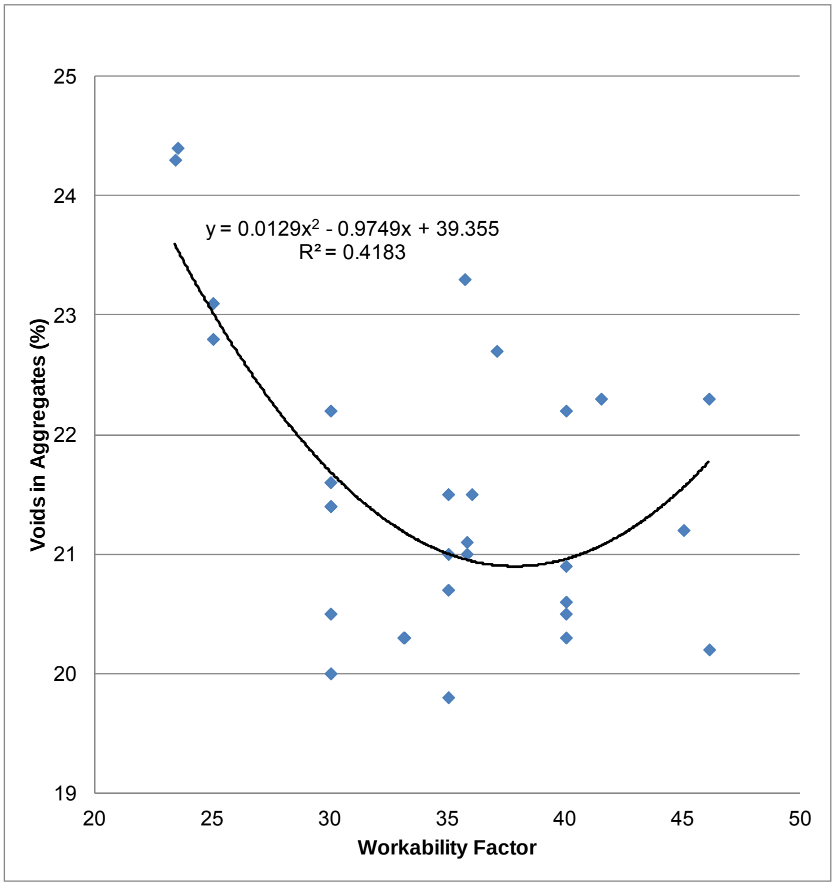

Figure 34 - Influence of Workability Factor on Voids in Aggregate

Workability Index

Categories had to be developed to compare mixture performance using workability. Based on the author's opinion, three categories of workability were achieved in this study including; low, moderate and high. See Table 16 for WI categories and the mixes associated with each category.

Table 16 - Workability Index

Workability Index (WI) (in.)	Category	Mixes
WI < 5	Low	5, 7, 8, 14, 20, 25
5 ≤ WI < 8	Moderate	1, 2, 3, 4, 9, 11, 12, 13, 16, 17, 19, 21, 23,
WI ≥ 8	High	6, 10, 15, 18, 22, 27, 29, 30

Each mixture's workability index (WI) is plotted on the CF chart and is presented in Figure 35. In addition, Figure 36 presents the correlation of WI to paste content. The only mix plotting within the MDOT elliptical limits on the CF chart that rated high in workability index is

Mix 30. Mix 30 is a repeat of Mix 3 with the addition of 1 ½ gallons of water per cubic yard of concrete. Since Mix 30 did not meet criteria of slump and w/c ratio established for the study, WI results are invalid for Mix 30. Mixes with coarseness and adjusted workability factors that plotted within the MDOT ellipse produced moderate WI ranging from 5 in. to 7.2 in.

Four mixes rated a high WI in Zone II include mixes 10, 15, 18, and 29. Since Mix 29 did not meet criteria for slump established for the study, WI results for Mix 29 are invalid. Additional high WI occurs in Zones "IV" and "III". Therefore, if the goal of the concrete mixture designer is to have the highest workability index, the target CF and AWF of the aggregate grading should plot between CF 40 and CF 50 within Zones II and III. High WI was also observed in Zone IV, but this zone should be avoided because of the high water demand associated with the excessive fines in this zone.

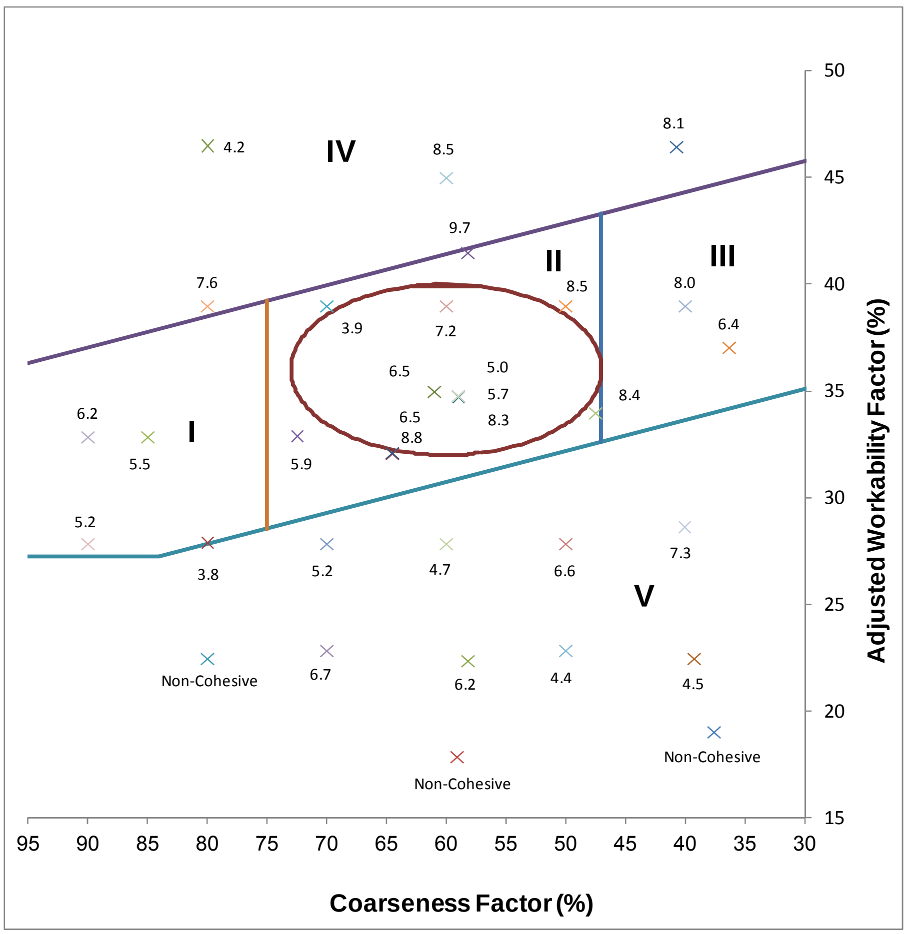

Figure 35 - Modified Coarseness Factor Chart (Workability Index)

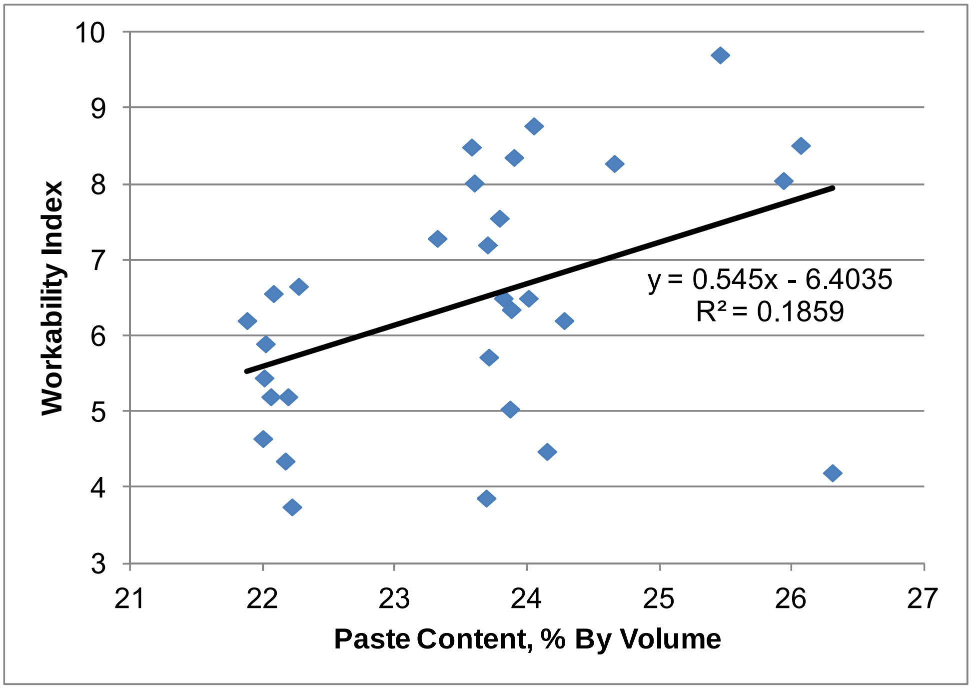

Figure 36 - Workability Index (WI) vs Paste Content

Compressive Strength

Compressive strength of concrete is influenced by all aspects of the concrete mixture. Water cementitious ratio and the type of aggregate both have influence on compressive strength. This study used a w/c ratio of 0.450 for all mixes except for Mix 30 which had a 0.473 w/c ratio. Mix 30 had a different w/c ratio because this mix was used to evaluate the impact of adding 1 ½ gallon of water to a cubic yard of concrete. Average twenty-eight day compressive strengths ranged from 4,433 psi (Mix 15) to 6,093 psi (Mix 20) even though a w/c cement ratio of 0.45 was used for all mixes except for Mix 30. This 1,660 psi difference in compressive strengths may be attributed to entrapped air, adjusted workability factor, shape of the combined percent retained chart, and the acceptable range of strengths of companion cylinders. A plot of average compressive strength versus age is presented in Figure 37 for all mixes. Figure numbers 38 through 42 present compressive strength versus age for mixes with cement contents of 484.1 PCY, 512.3 PCY, 526.4 PCY, 564 PCY, and 578.1 PCY, respectfully.

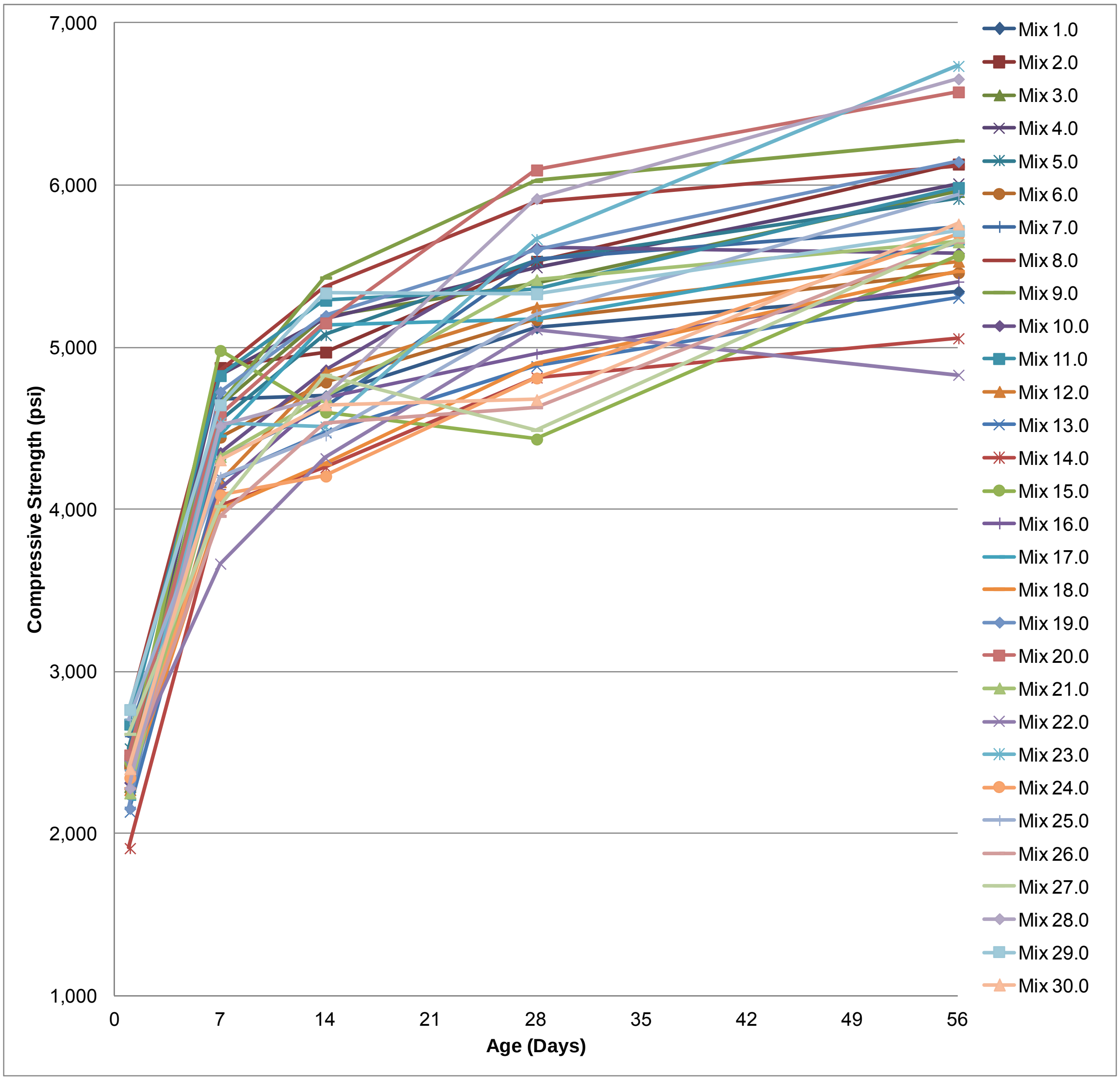

Figure 37 - Compressive Strength vs Age - All Mixes

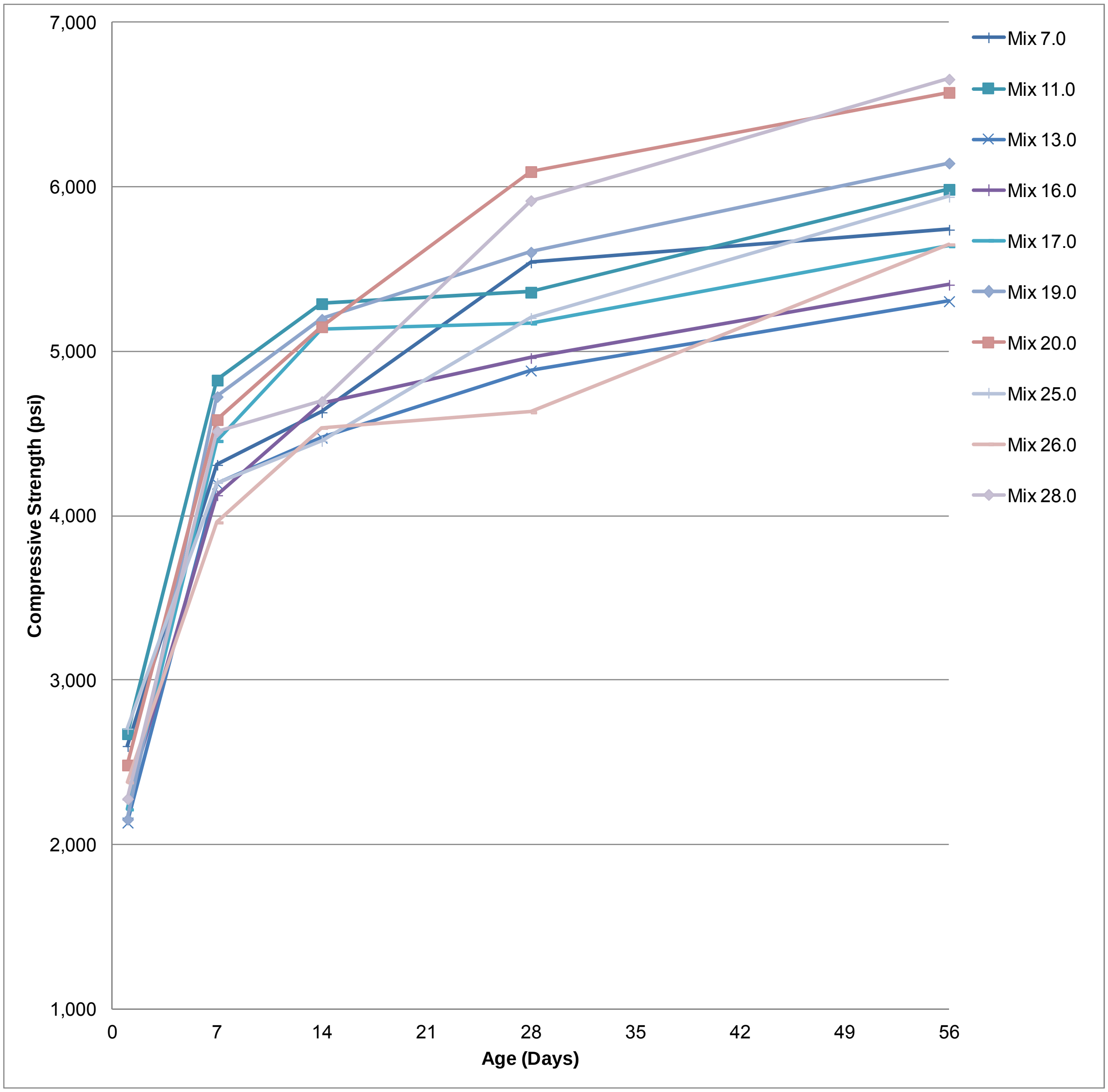

Figure 38 - Compressive Strength vs Age - Mixes with 484.1 PCY Cement

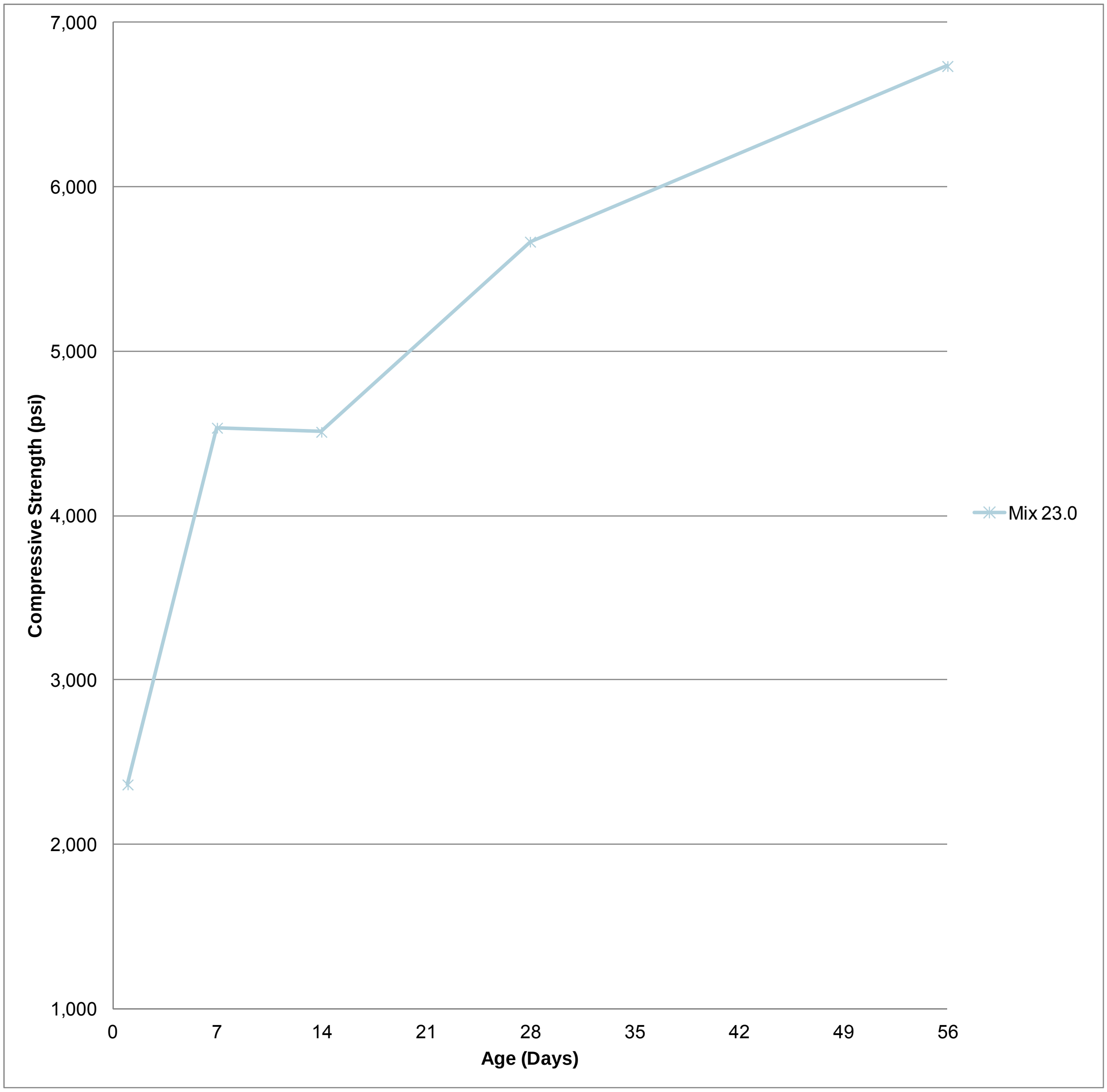

Figure 39 - Compressive Strength vs Age - Mixes with 512.3 PCY Cement

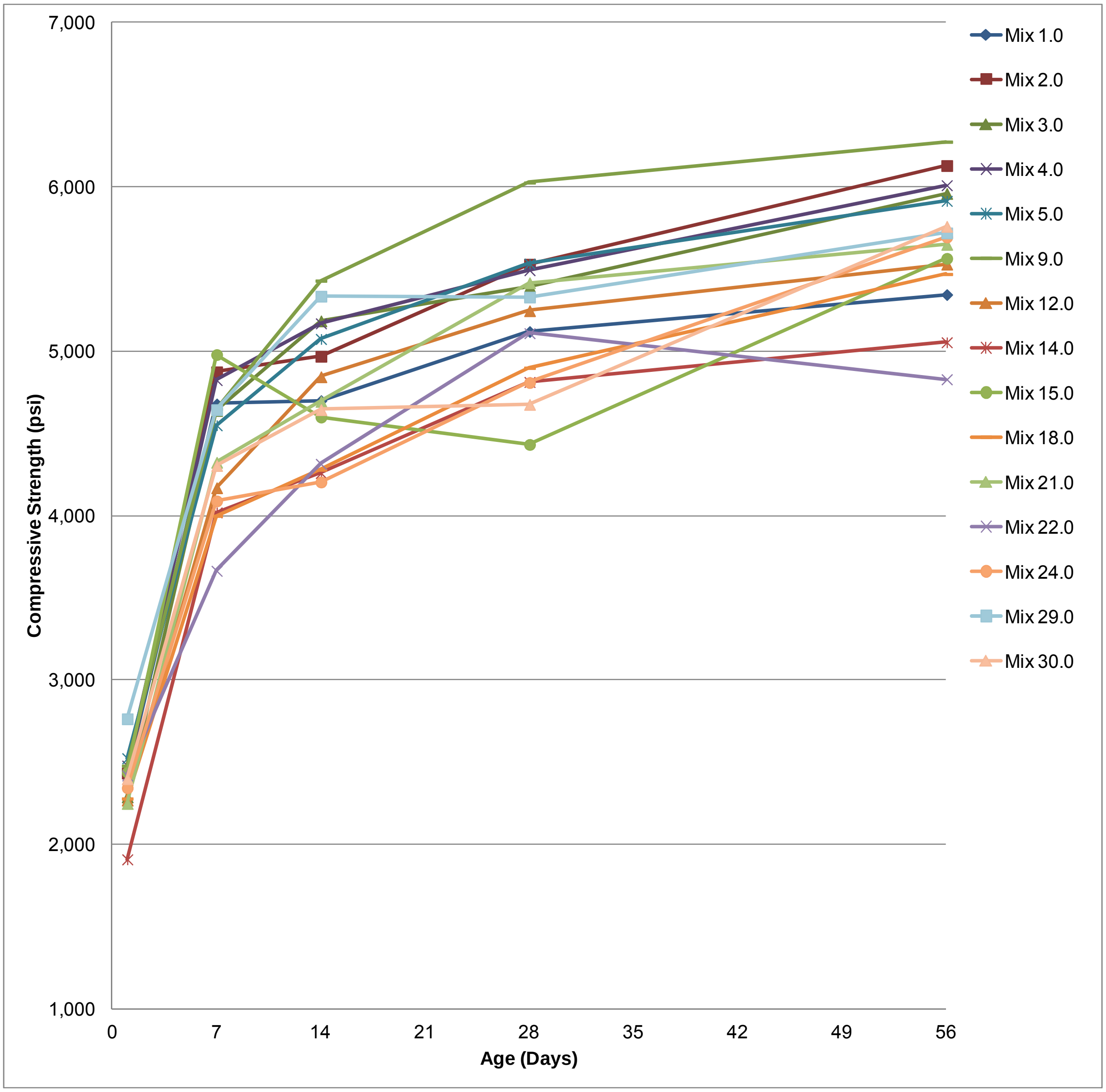

Figure 40 - Compressive Strength vs Age - Mixes with 526.4 PCY Cement

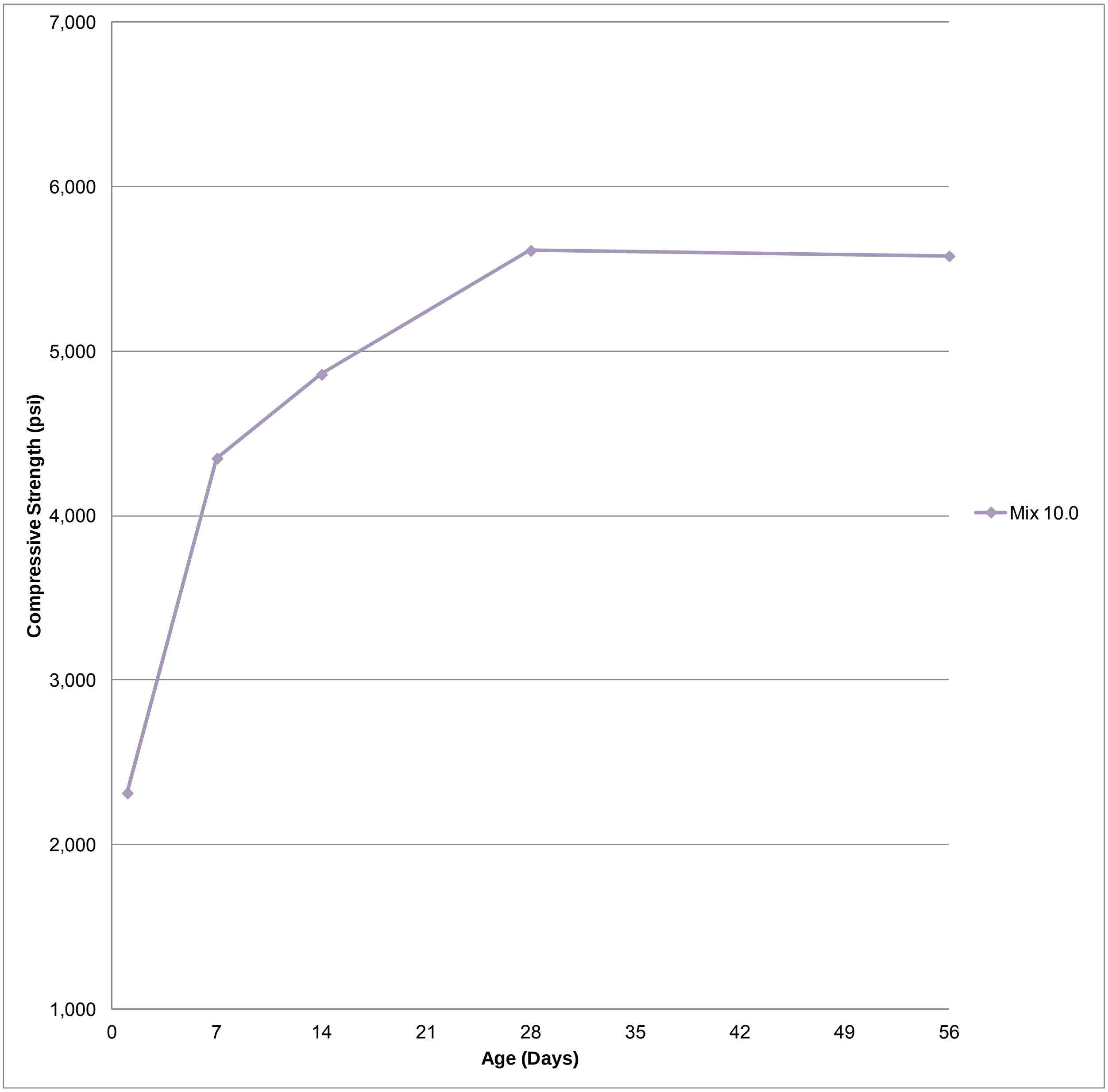

Figure 41 - Compressive Strength vs Age - Mixes with 564 PCY Cement

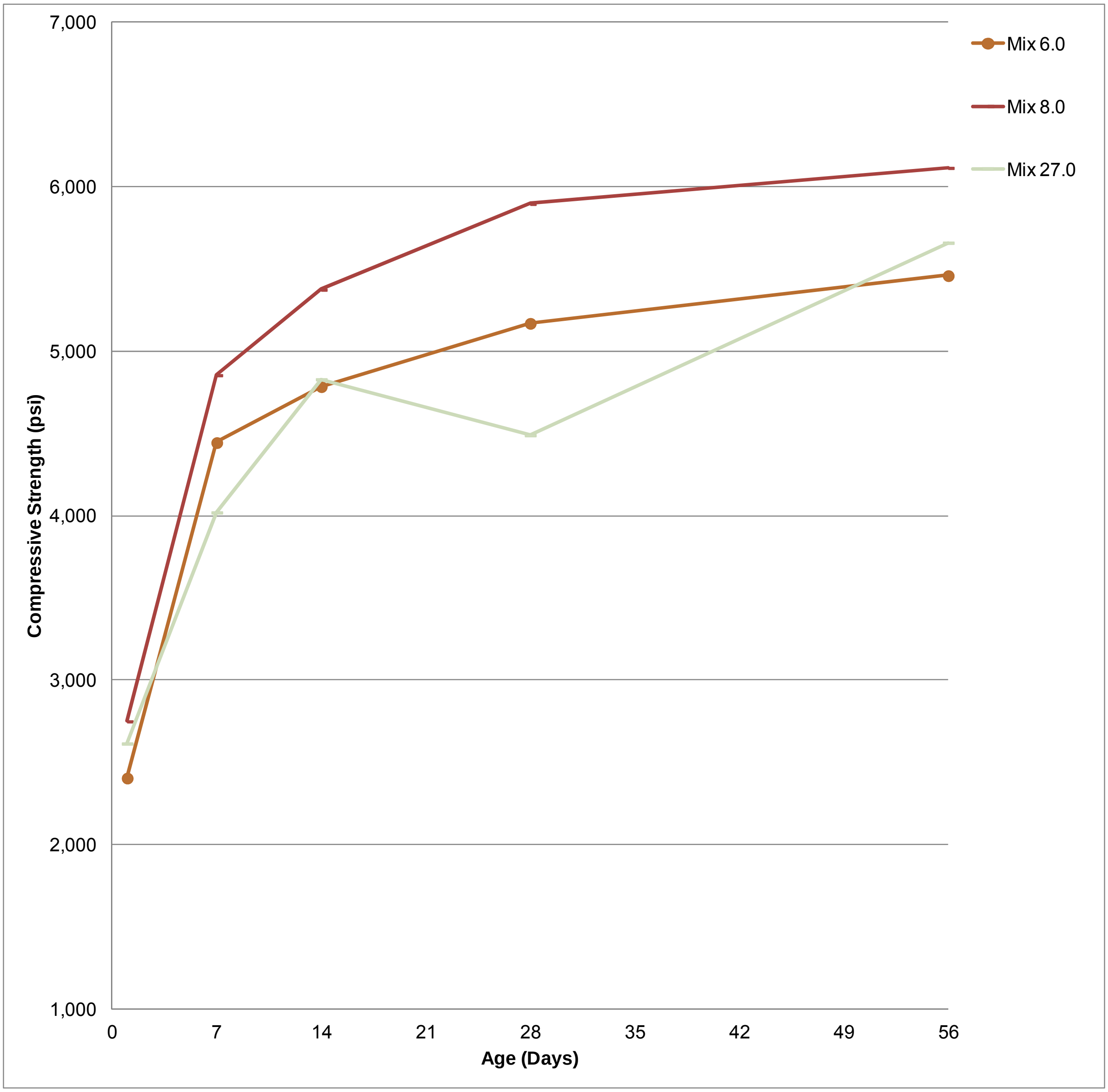

Figure 42 - Compressive Strength vs Age - Mixes with 578.1 PCY Cement

Figure 43 presents 28 day compressive strengths of all mixes versus 448 day shrinkage. These data show that there is no apparent correlation between compressive strength and 448 day shrinkage.

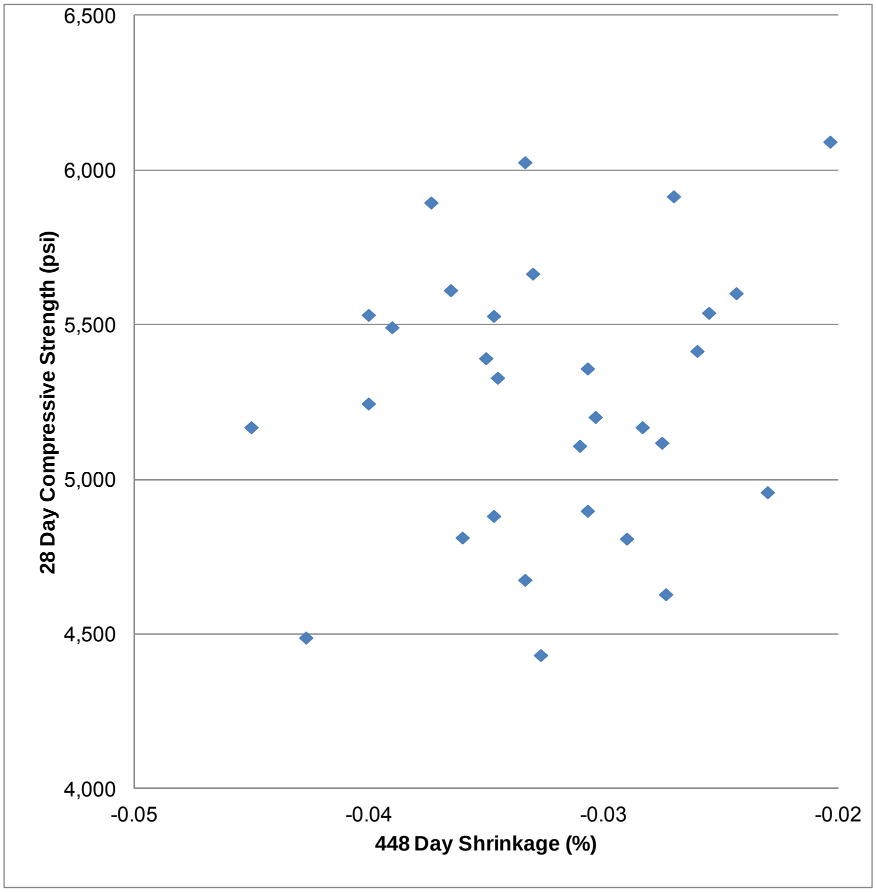

Figure 43 - 28 Day Compressive Strength vs 448 Day Shrinkage

<u>Influence of Entrapped Air.</u>

There are two types of air in concrete including entrained air and entrapped air. Entrained air is generated in concrete with chemical admixtures to provide durability for concrete that is exposed to cycles of freezing and thawing. Entrained air was not used in this study in order to reduce variability between mixes. All air reported herein is entrapped air that is inherent in all concrete mixtures. Air results in void pockets in the cement paste that weakens the paste. As the air content of the paste increases, compressive strength decreases. Average 28 day compressive strength versus air content is presented in Figure 44. This figure represents mixes that contain 526.4 pounds of cement per cubic yard of concrete including mixes 1, 2, 3, 4, 5, 9, 12, 14, 15, 18, 21, 22, 24, 29, and 30. This figure shows a correlation between entrapped air voids and average compressive strengths. The average compressive strengths decrease as entrapped air voids increase.

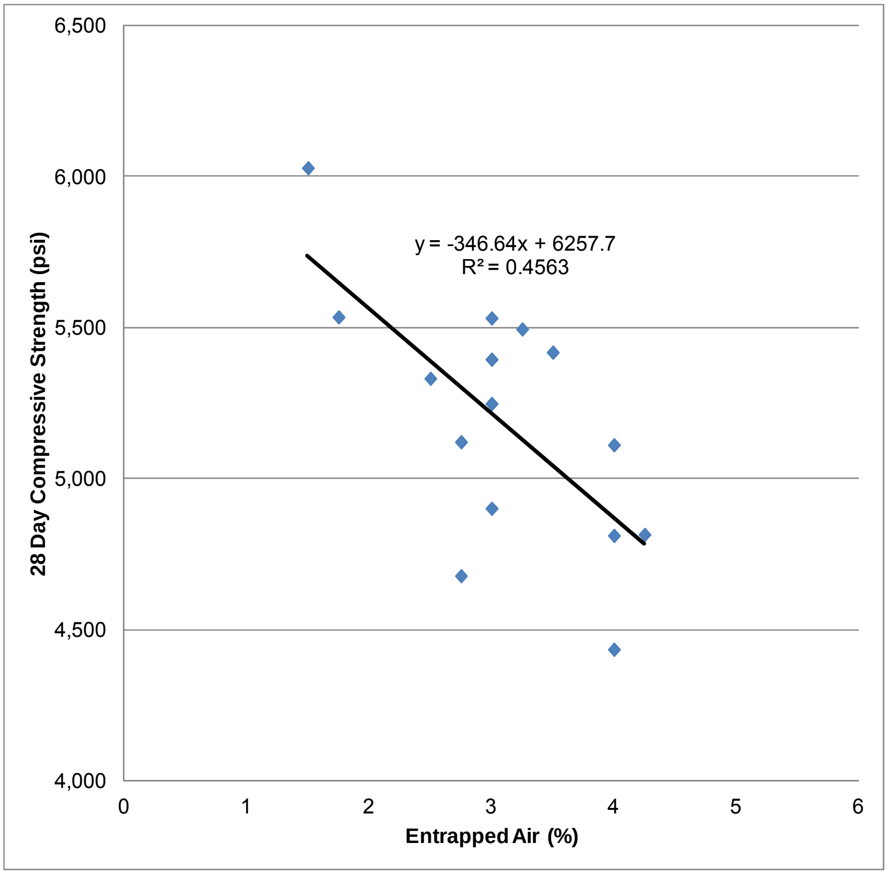

Figure 44 - Average 28 Day Compressive Strength VS Entrapped Air (Mixes with 526.4 PCY)

Figure 45 presents a plot of entrapped air versus AWF. Entrapped air increases as AWF increases. AWF indicates the percentage of aggregate particles that are smaller than a No. 8 sieve relative to the total volume of aggregate in the concrete mixture. As AWF increases, the total amount of fine material in the mixture increases. This correlation between entrapped air and AWF factor may be a due to the increased surface area of the aggregate portion of the mixture. Increased surface area requires more cement paste to coat aggregate particles and provides additional space for entrapped air voids to develop.

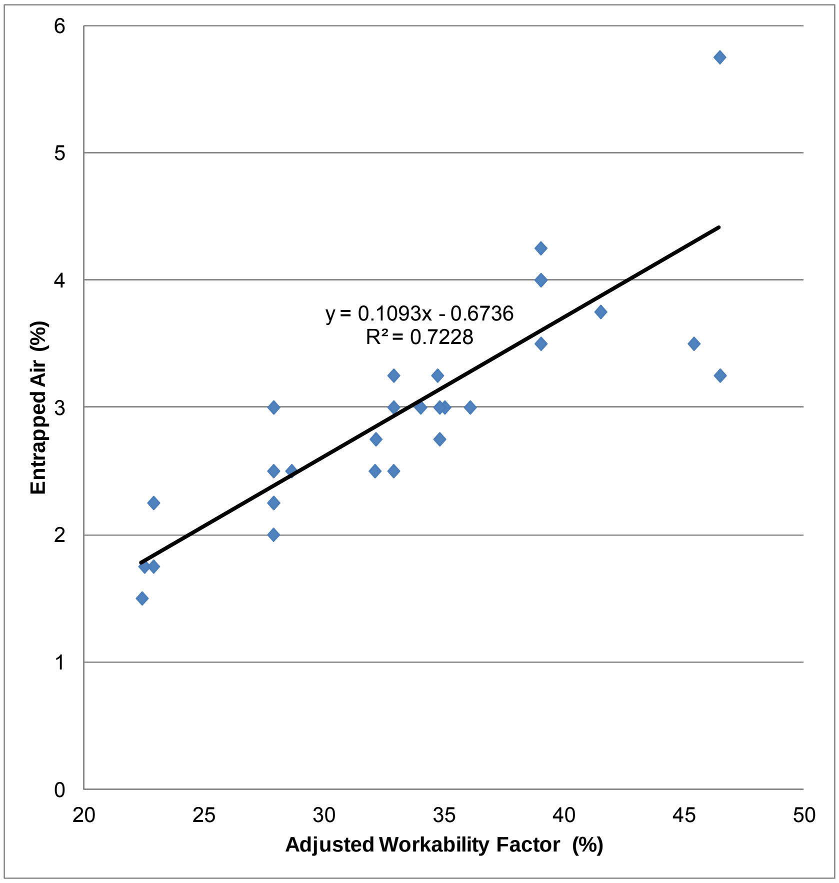

Figure 45 - Entrapped Air VS AWF (All Mixes)

Influences of Combined Percent Retained Chart.

Mixes 1 and 3 were repeated in Mixes 29 and 4, respectively. The primary difference in the mixes is the shape of the combined percent retained charts. Average compressive strengths and combined percent retained charts of Mixes 1 and 29 are presented in Figures 46 and 47, respectively. Average compressive strength of Mixes 3 and 4 and combined percent retained charts are presented in Figures 48 and 49, respectively. The average twenty-eight day compressive strength of Mix 1 is 5,120 psi and the average for Mix 29 is 5,330 psi with a difference of 210 psi. The average twenty-eight day compressive strength of Mix 3 was 5,393 psi and the average for Mix 29 was 5,493 psi with a difference of 100 psi. Based on compressive strength data of Mixes 1, 3, 4, and 29, the shape of the combined percent retained chart has little to no influence on compressive strength.

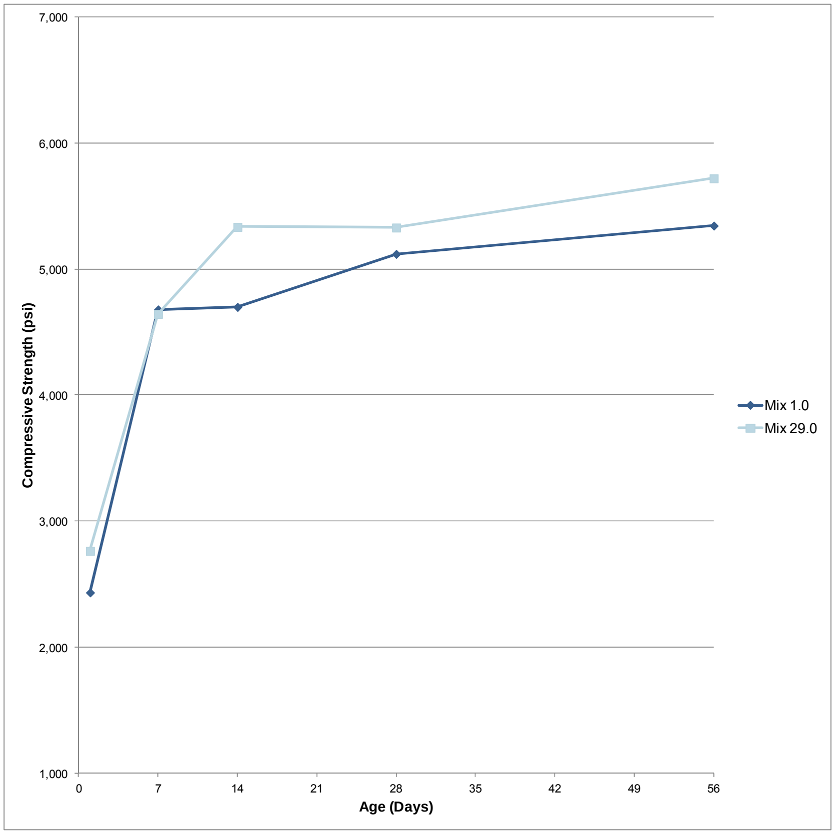

Figure 46 - Average Compressive Strength vs Age (Mixes 1 and 29)

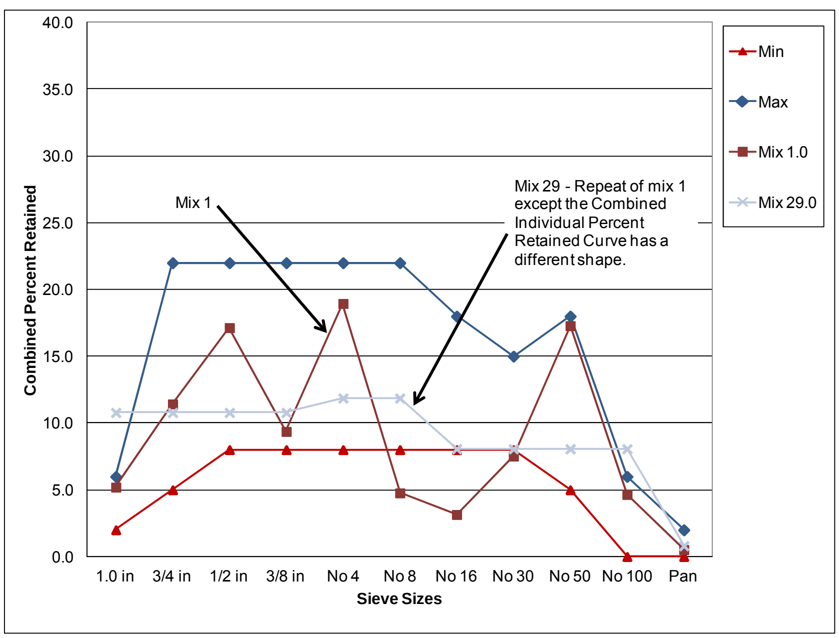

Figure 47 - Combined Percent Retained Chart - Mixes 1 and 29 (Repeated Figure)

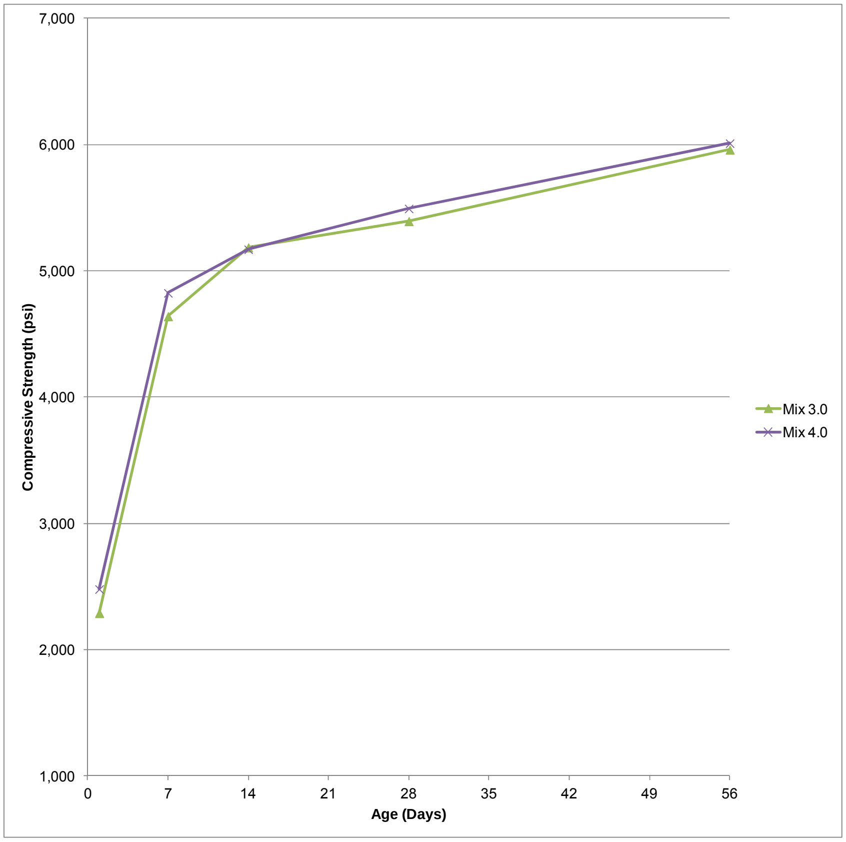

Figure 48 - Average Compressive Strength vs Age (Mixes 3 and 4)

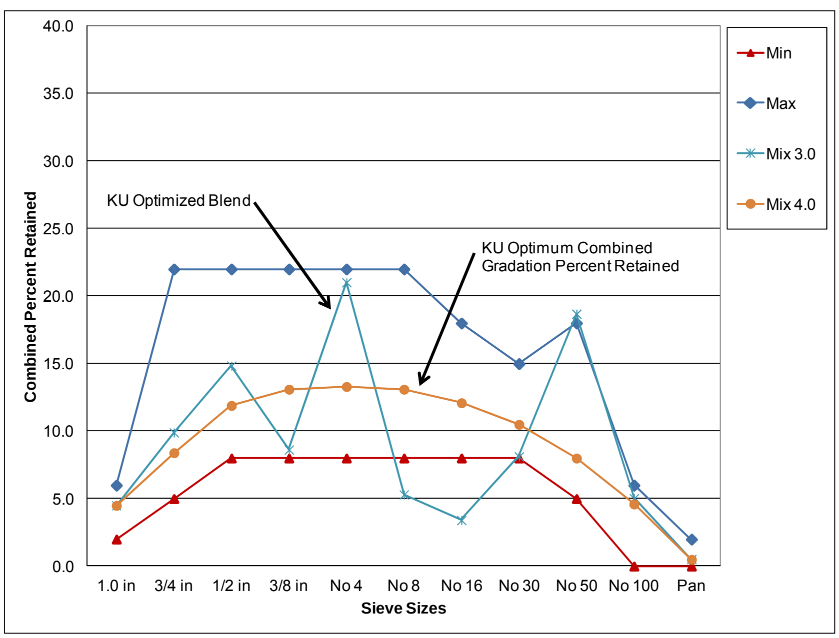

Figure 49 - Combined Percent Retained Chart - Mixes 3 and 4 (Repeated Figure)

Influence of CF and AWF.

Figures 50 through 54 present data showing the influence of CF and AWF on 28 day compressive strength. There does not appear to be any correlation between coarseness factor (CF) and compressive strength as shown in Figures 50 and 52. There is better correlation between compressive strength and adjusted workability factor (AWF) as presented in Figures 51 and 53 relative to compressive strength and CF. As AWF decreases, compressive strength increases. This is primarily due to increased entrapped air voids associated with higher adjusted workability factors.

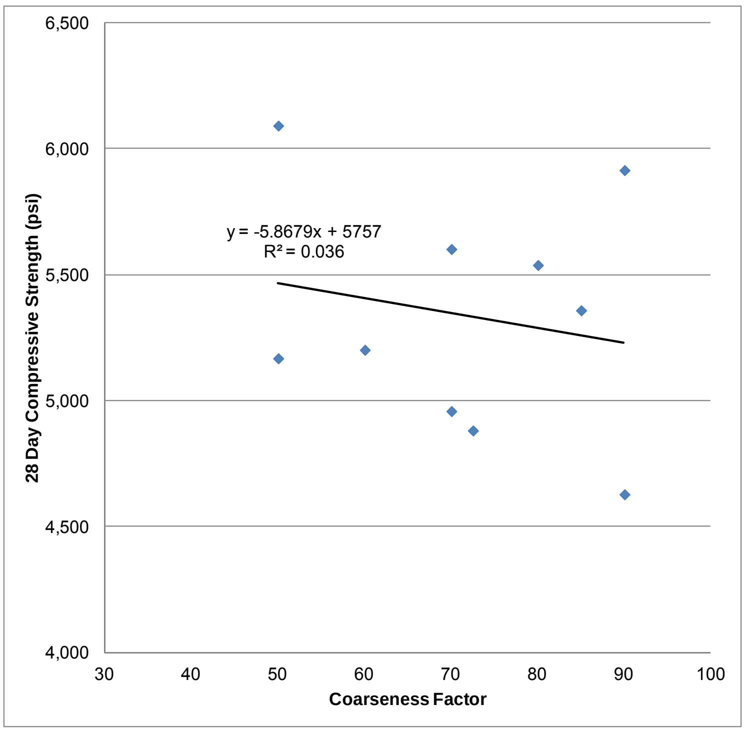

Figure 50 - Average 28 Day Compressive Strength vs CF (526.4 PCY)

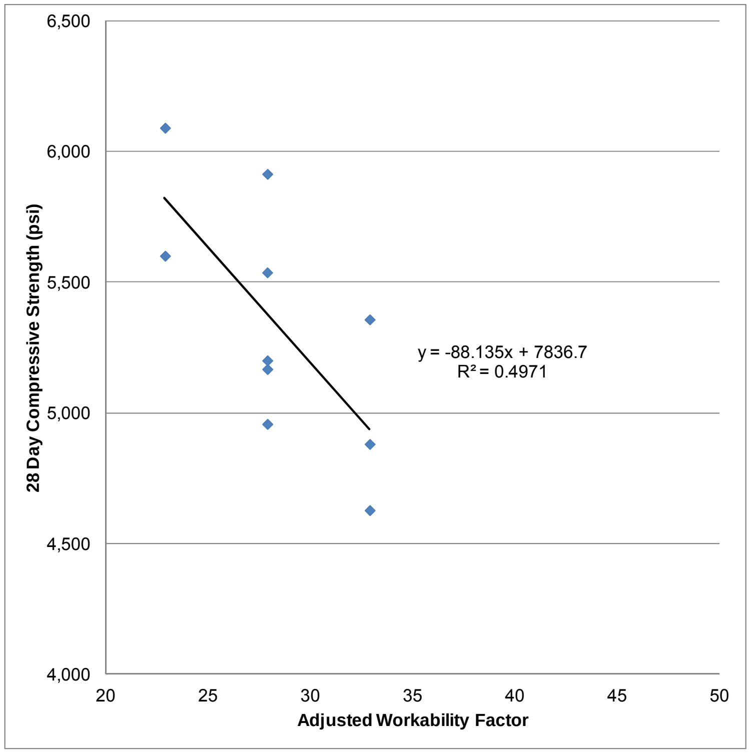

Figure 51 - Average 28 Day Compressive Strength vs AWF (526.4 PCY)

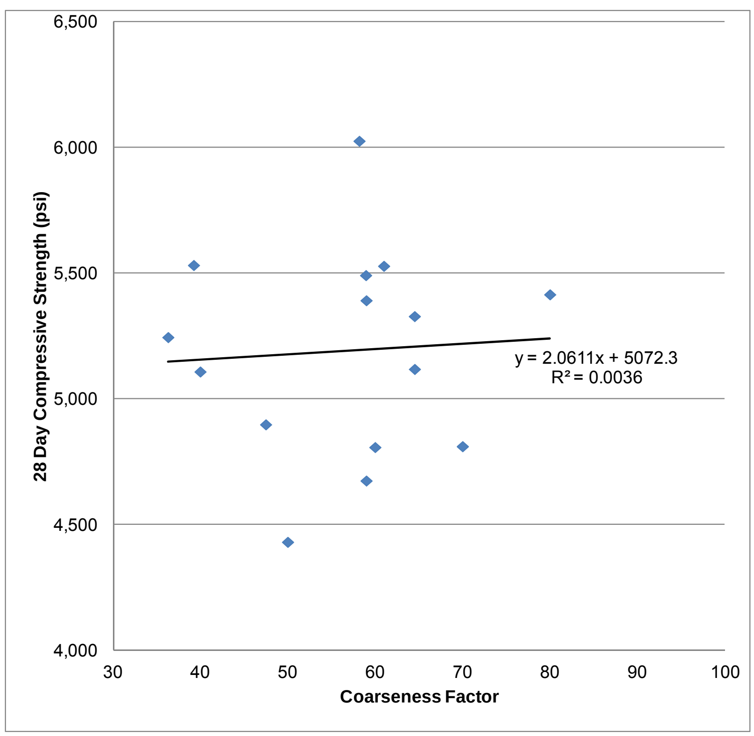

Figure 52 - Average 28 Day Compressive Strength vs CF (578.1 PCY)

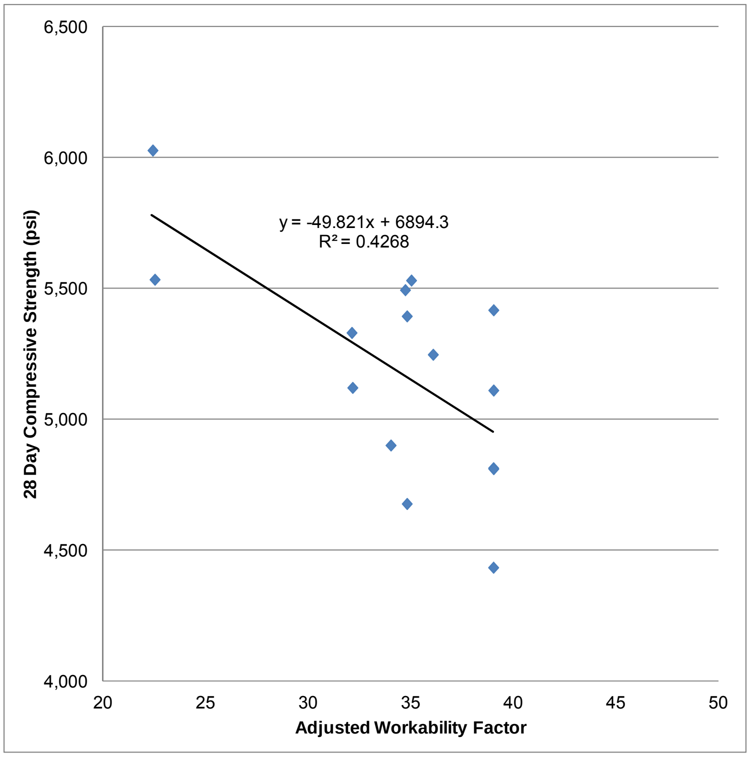

Figure 53 - Average 28 Day Compressive Strength vs AWF (578.1 PCY)

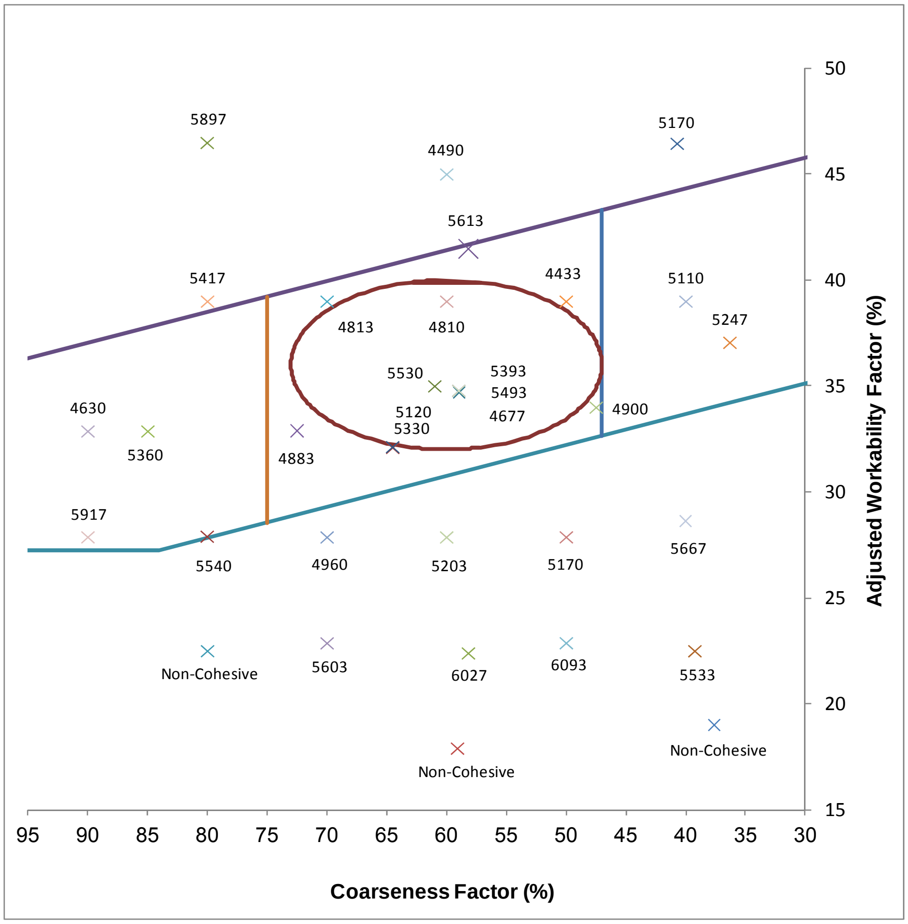

Figure 54 - Modified Coarseness Factor Chart (28 Day Compressive Strengths)

Length Change

All Mixes.

The average length change versus age is presented in Figure 55 for all thirty mixes. The ultimate percent shrinkage in this study occurred at 448 days of curing in a temperature and humidity controlled environment. Shrinkage ranged from (-) 0.0203 percent (Mix 20) to (-) 0.0450 percent (Mix 6). Length change results provided herein are measured and calculated to the nearest ten thousandth of a percent in order to show shrinkage values for each mix. AASHTO T 160 / ASTM C 157 notes that average percent length change is to be reported to the nearest one hundredth of a percent. If shrinkage results of this study were rounded to the nearest one hundredth of a percent, three percentages could be used to describe the shrinkage determined. These include 0.02, 0.03, and .04 percent.

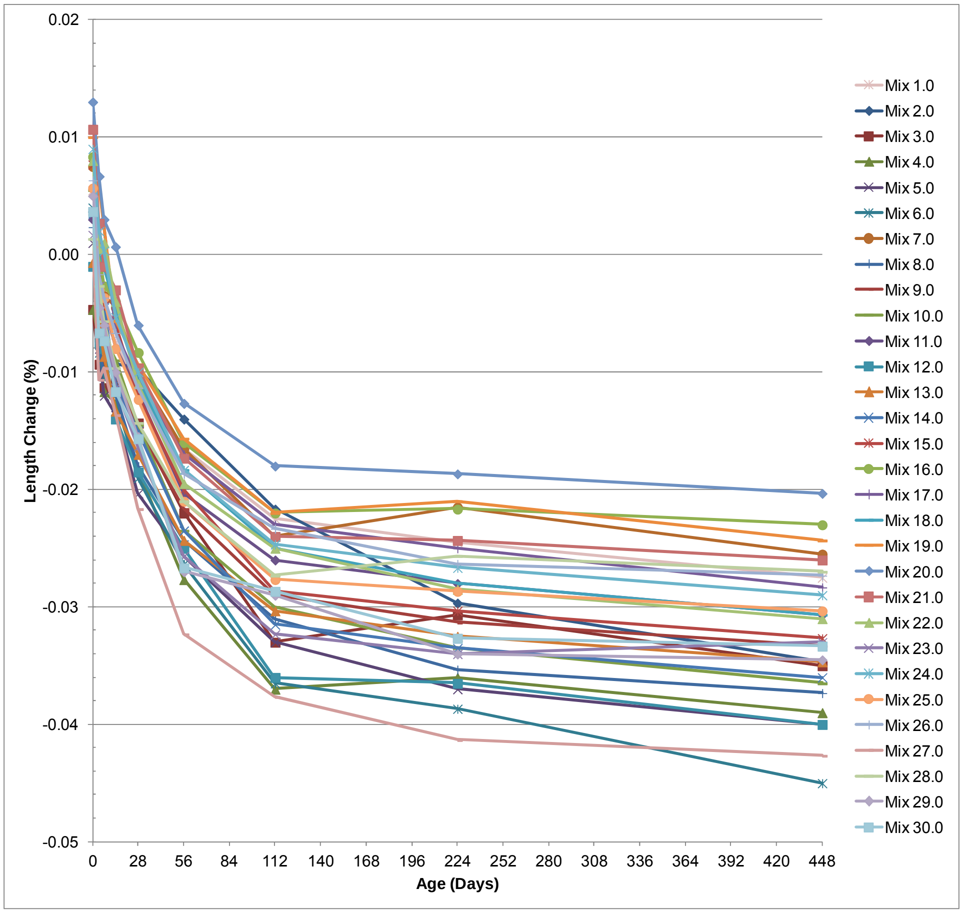

Figure 55 - Average Length Change vs Age (All Mixes)

Influence of Cement Content.

The cement and water contents were adjusted as required to maintain a constant w/c ratio of 0.45 (except for Mix 30) while producing a slump of 2 ½ in. to 3 ½ in. To accomplish this, five cement contents had to be used for the thirty mixes of this study. Table 17 presents cement contents and associated mixes.

Table 17 - Cement Content and Associated Mixes

Cement Content (lbs/ft^3)	Mixes
484.1	7, 11, 13, 16, 17, 19, 20, 25, 26, 28
512.3	23
526.4	1, 2, 3, 4, 5, 9, 12, 14, 15, 18, 21, 22, 24, 29, 30
564	10
578.1	6, 8, 27

Figures 56 through 58 present length change versus age for cement contents of 484.1, 526.4, and 578.1 PCY, respectively. The average length change increases as cement and paste content increases. Table 18 presents a summary of percent shrinkage for mixes with cement contents of 484.1, 512.3, 526.4, 564, and 578.1 PCY. The difference in minimum and maximum percent shrinkage shown in Table 18 may be attributed to the surface area of aggregate particles, entrapped air content, and void content between aggregate particles that is created by combined aggregate gradation. See Chapter 7 for more information on the influence of voids in aggregates on shrinkage. The maximum difference in shrinkage that can be attributed to these factors in this study is (-) 0.0144 percent. These data confirm that cement content and aggregate particle size distribution have influence on shrinkage of concrete.

Table 18 – Percent Length Change vs Cement Content

Cement Content (lbs/yd^3)	Average Length Change	Minimum Length Change (%)	Maximum Length Change (%)	Difference (%)
484.1	-0.0272	-0.0203	-0.0347	-0.0144
512.3[3]	-0.0330	-0.0330	-0.0330	0
526.4	-0.0335	-0.0260	-0.0400	-0.0140
564[3]	-0.0365	-0.0365	-0.0365	0
578.1	-0.0417	-0.0373	-0.0417	-0.0044

Notes:

3. This cement content was used for one mix only.

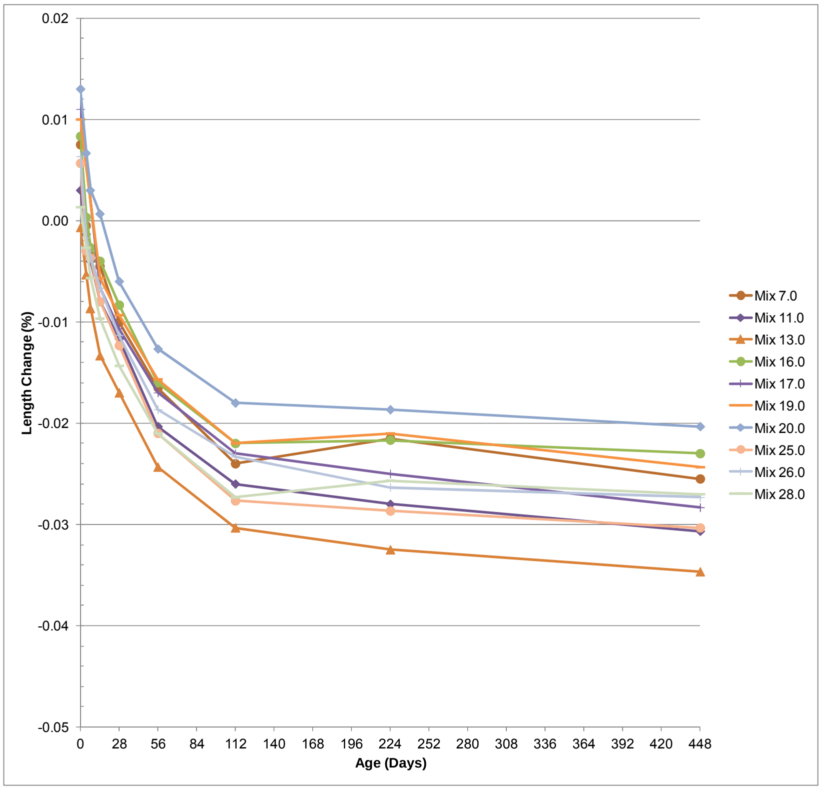

Figure 56 - Average Length Change vs Age (484.1 PCY)

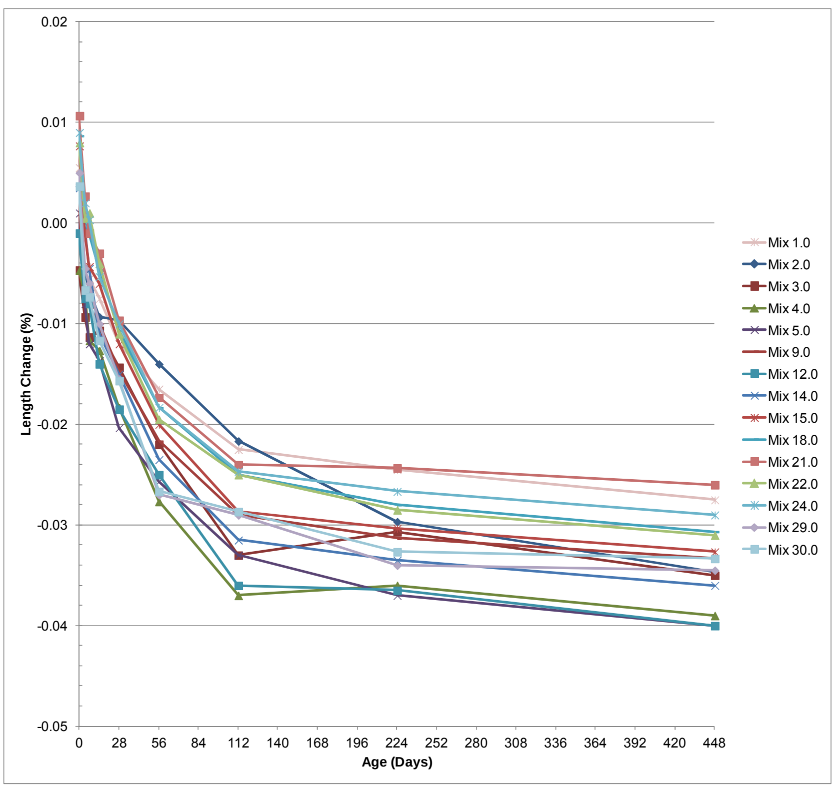

Figure 57 - Average Length Change vs Age (526.4 PCY)

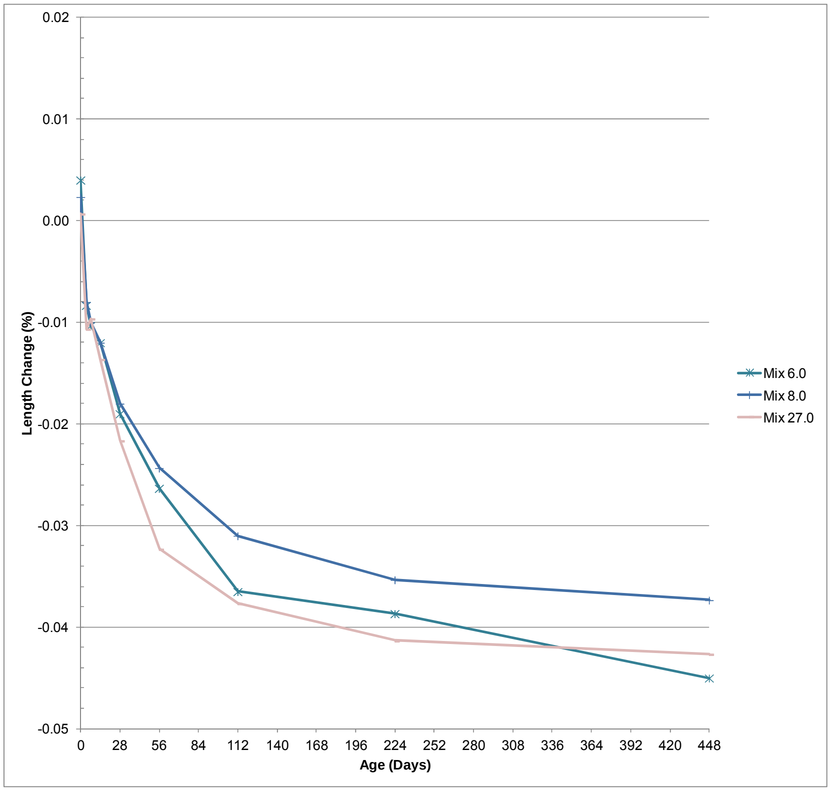

Figure 58 - Average Length Change vs Age (578.1 PCY)

<u>Influence of CF and AWF.</u>

Figures 59 and 60 present the influence of CF and AWF on shrinkage, respectfully. Figure 59 presents a correlation between the average shrinkage at 448 days and CF. As coarseness factor increases, there is a decrease in the average percent shrinkage. Figure 60 presents a correlation between average shrinkage at 448 days and adjusted workability factor showing that as AWF increases, shrinkage increases. These data show a better correlation between AWF and shrinkage at 448 days than the correlations with respect to CF and 448 day shrinkage. Figure 61 presents average 448 day shrinkage data plotted on the CF chart.

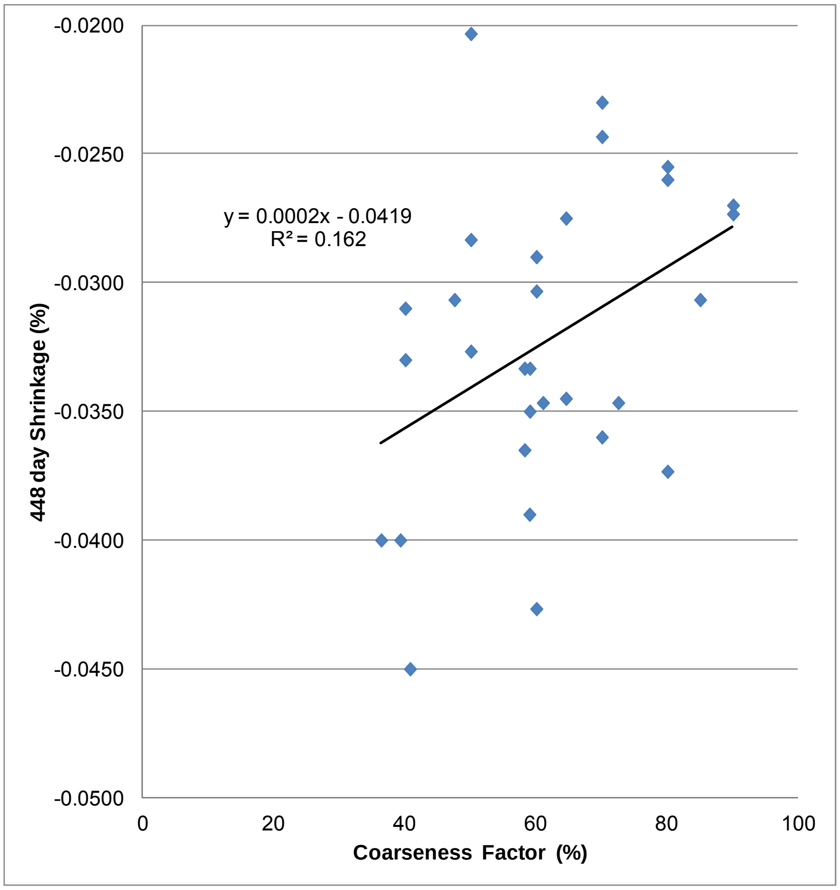

Figure 59 - Average Percent Shrinkage vs CF

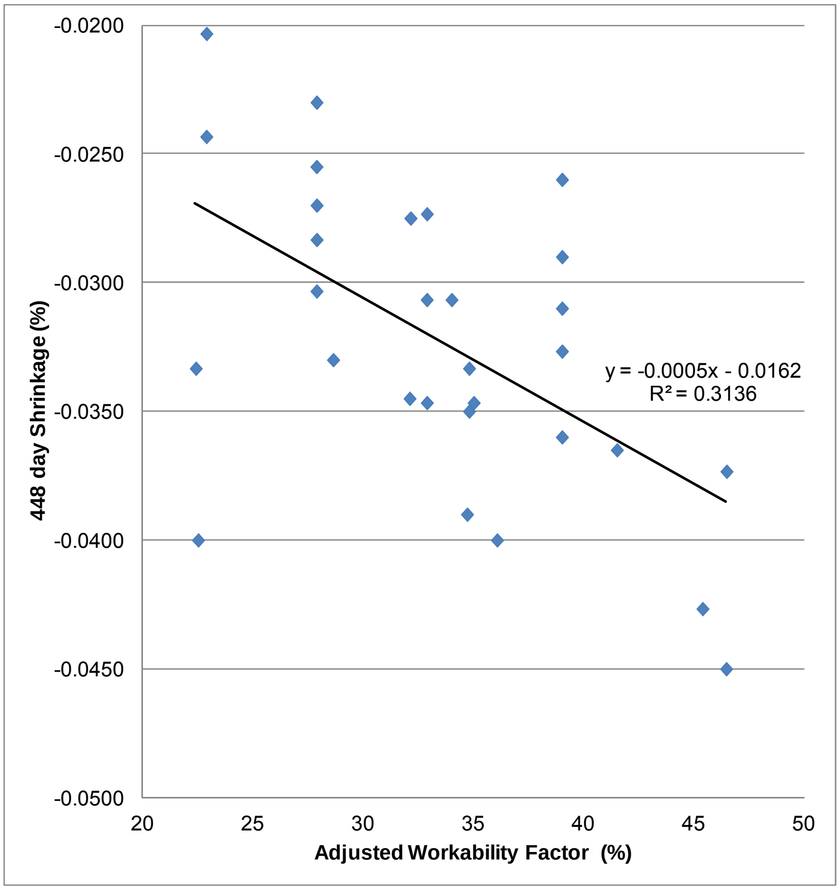

Figure 60 - Average Percent Shrinkage vs AWF

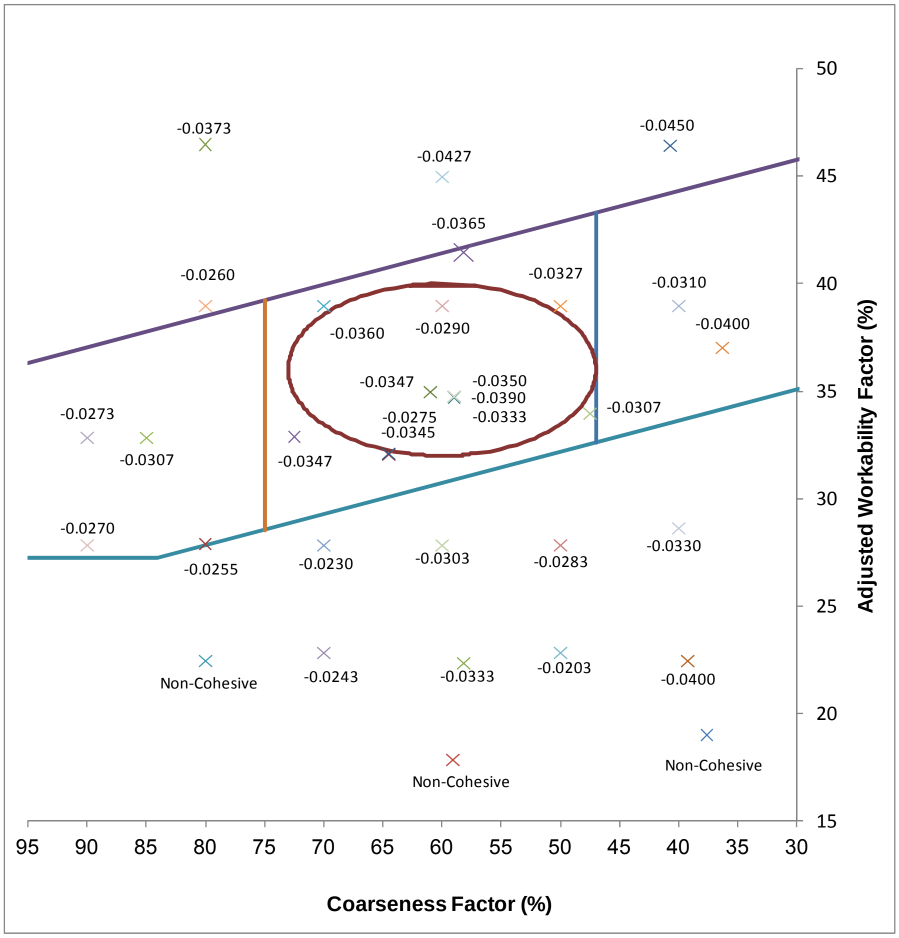

Figure 61 - Modified Coarseness Factor Chart (448 Day Shrinkage)

<u>Influence of Adding 1 ½ Gallons of Water PCY.</u>

Mix 30 was a repeat of Mix 3 and was developed to determined the impact of adding 1 ½ gallons of water to a cubic yard to concrete. While we do not have enough data to draw conclusions and recommendations from this limited data, results from this testing are presented in Figures 62 and 63. Based on this limited data, adding 1 ½ gallons of water per cubic yard of concrete in Mix 30 reduces the average 28 day compressive strength by 13.3 percent when compared to Mix 3. Adding 1 ½ gallons of water increased the slump by 2 1/4 in. and had little impact on length change (shrinkage) relative to Mix 3 as shown in Figure 63.

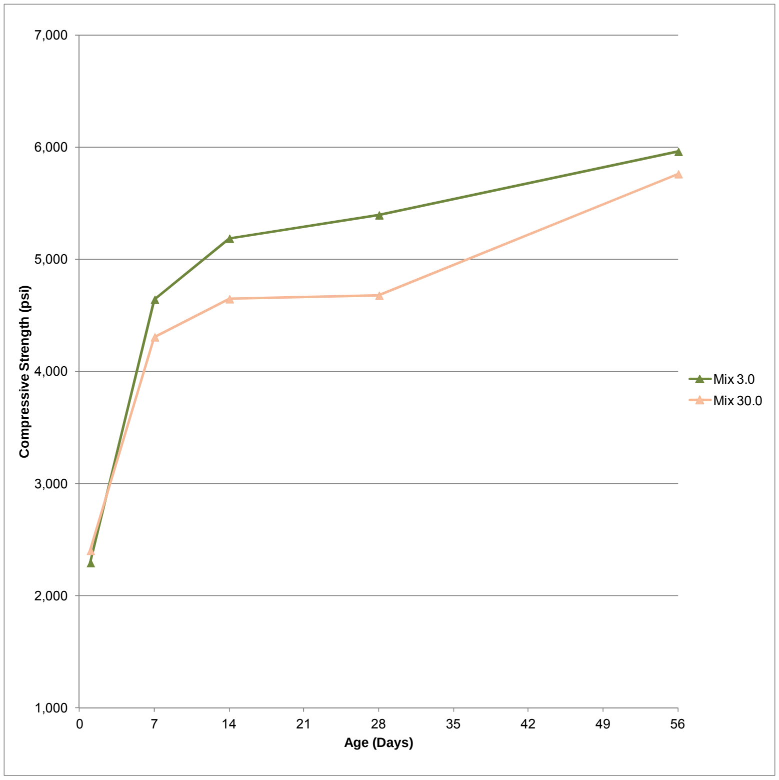

Figure 62 - Average Compressive Strength VS Age (Mixes 3 and 30)

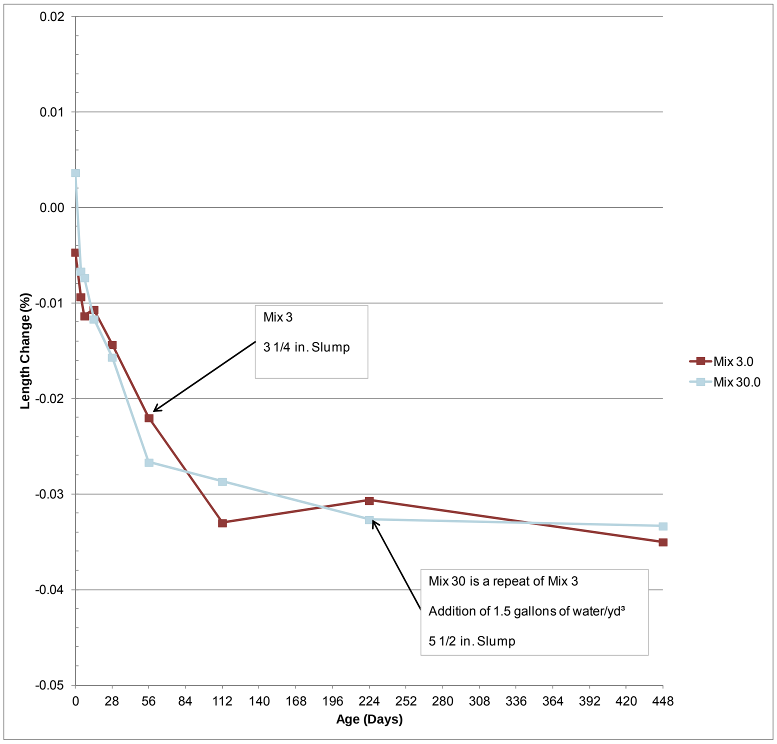

Figure 63 - Average Length Change VS Age (Mixes 3 and 30)

Chapter 7 – Analysis of Shrinkage Data

Influence of Aggregate Gradation

Modified Coarseness Factor Chart.

Data generated in this study show that the primary factor that influences shrinkage is paste content of the mixture. The amount of cement needed in a mixture is influenced by finishability, durability, workability, and strength. Cement content is also influenced by combined aggregate gradation that can be quantified by the modified CF chart. Water and cement have to be increased for mixtures with CF and AWF that plot in Zone IV when compared to mixtures whose CF and AWF plot within MDOT's elliptical limits. This increase in water is due to the amount of fines associated with Zone IV which requires additional water to produce similar slumps. Water and cement can be reduced for mixtures with CF and AWF plotting in certain areas of Zones I, V, and trend bar when compared to mixtures whose CF and AWF plot within MDOT's elliptical limits on the modified CF chart. These areas are noted in Figure 25 by mixes with cement contents that are less than 526.4 PCY. This is due to the decrease in water content of these areas of Zones I, V, and trend bar required to produce similar slumps as mixtures whose CF and AWF plot within MDOT's elliptical limits. Reducing paste content in concrete mixtures results in reduced shrinkage.

Data in this study show that cement content can be increased or decreased by 94 (one sack of cement) pounds per cubic yard. This increase or decrease is influenced by the mixture's combined aggregate gradation position on the modified CF chart.

Cement content can be increased by 51.7 pounds per cubic yard or decreased by 42.3 pounds per cubic yard based on the location of the mixture's CF and AWF on the modified CF chart relative to a mixture with aggregate gradation plotting within MDOT's elliptical limits. These areas are noted in Figure 25 by mixes with cement contents that are less than 526.4 PCY (decrease in cement) and cement contents that are greater than 526.4 PCY (increase in cement).

Figure 64 presents the average percent shrinkage versus cement content for mixtures containing 484.1, 512.3, 526.1 (except for Mix 30), 564, and 578.1 pounds of cement per cubic yard of concrete. This figure shows that shrinkage increases as cement content increases. Using the equation provided in Figure 64, reducing cement content from 526.4 PCY to 484.1 PCY (42.3 PCY) (less than half a sack of cement) results in a decrease in shrinkage of 0.0042 percent.

The average 448 day shrinkage for Mixes 2 and 4 was 0.0369 percent. Mixes 2 and 4 plotted near the center of MDOT's elliptical limits on the modified CF chart and met MDOT's requirements for combined percent retained on individual sieves except for the pan material on Mix 2. This average can be used to calculate the percent change in shrinkage that can be expected if cement content is reduced by 42.3 pounds per cubic yard of concrete by developing mixtures with coarseness factors and adjusted workability factors that plot in certain areas of Zones I, V, and trend bar instead of plotting within MDOT's elliptical limits. This reduction in shrinkage is 11.4 percent. See calculation below:

$$\left[\frac{0.0042}{0.0369}\right] x\,100 = 11.4\%$$

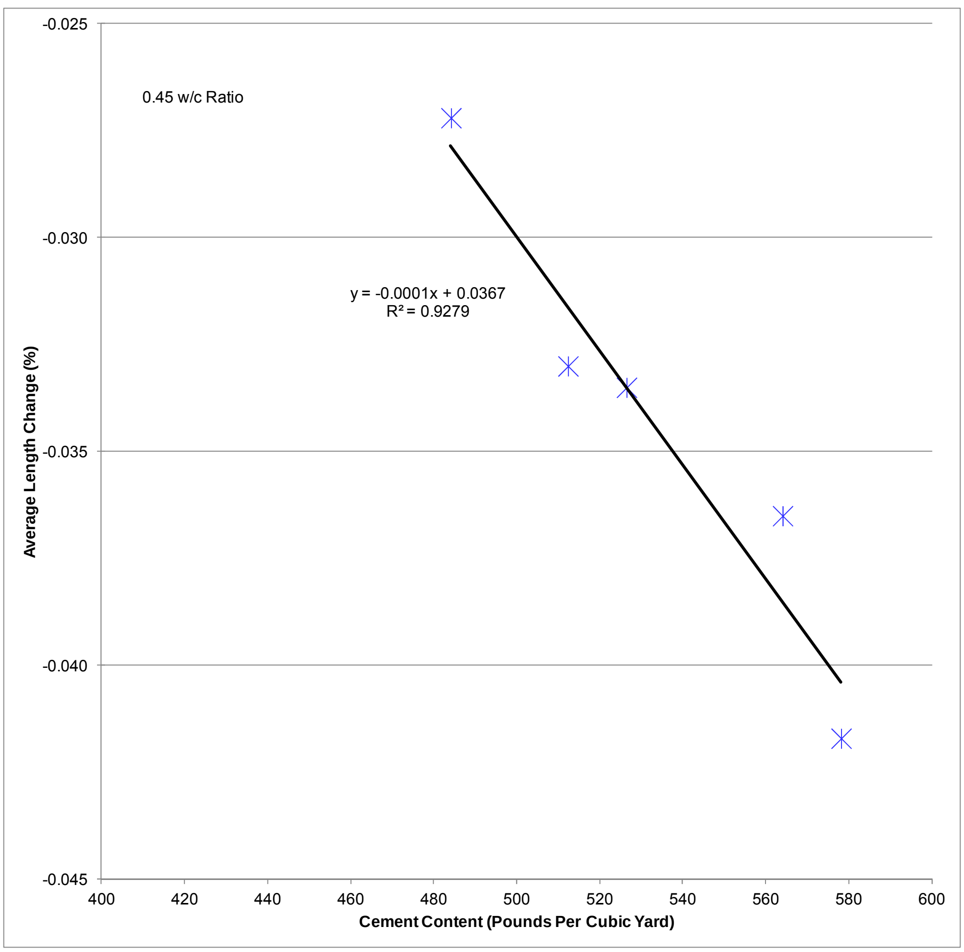

Figure 64 – Average Percent Shrinkage vs Cement Content

Voids in Aggregates

Length change of concrete is influenced by the void space between aggregate particles. This void space is filled with cement paste shrinks when exposed to drying conditions. The more void space that is created between aggregate particles the more cement paste has to be used to fill the void space. Figures 65 through 67 present average percent length change versus void space of aggregates for mixtures containing 484.1, 564, and 578.1 PCY of cement, respectively. Figure 68 presents average percent length change versus void space of aggregates for all mixes. These data show a correlation between length change and voids in aggregate. As void content in aggregates increase, length change (shrinkage) increases. In order to reduce the percent length change by 0.01 percent, the void content in aggregates would have to be reduced by 4.5 percent as shown in Figure 68.

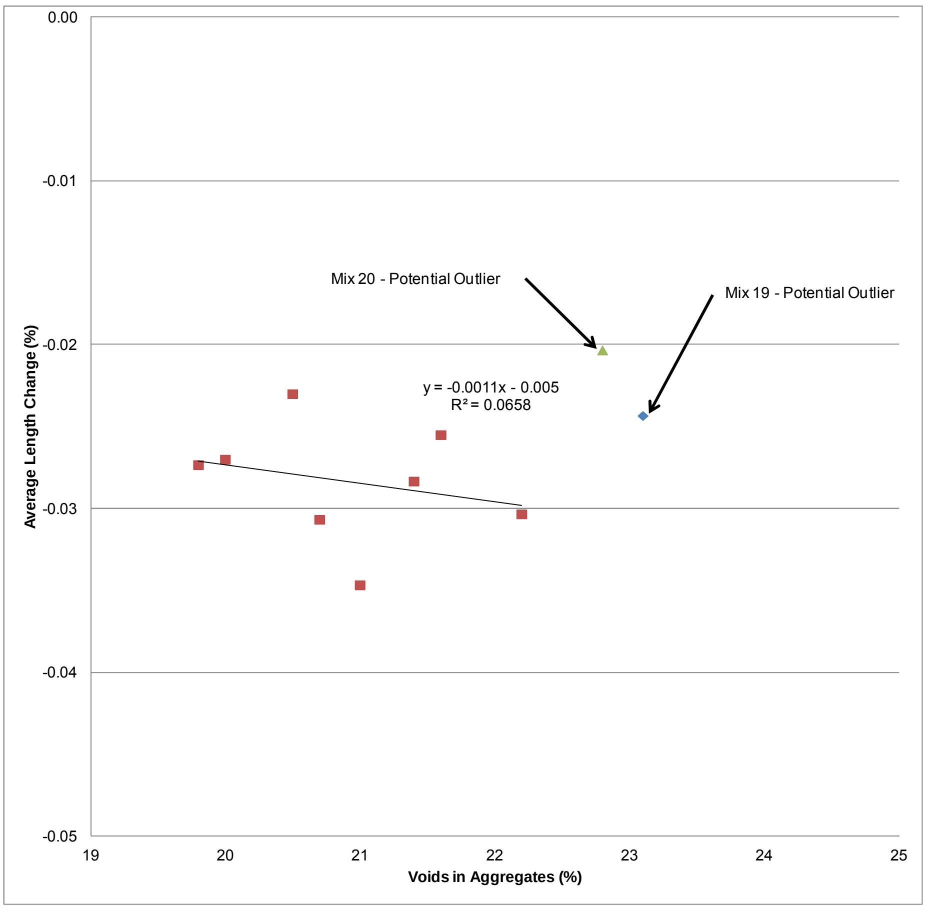

Figure 65 - Average Length Change vs Voids in Aggregates (484.1 PCY)

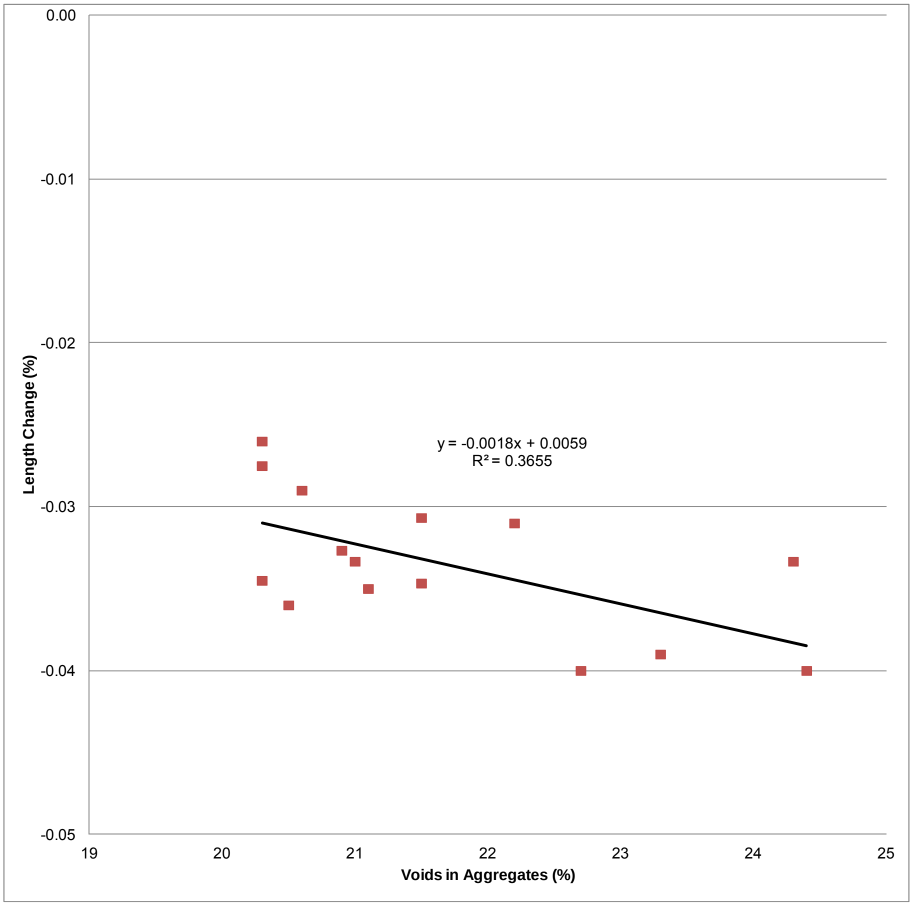

Figure 66 - Average Length Change vs Voids in Aggregates (526.4 PCY)

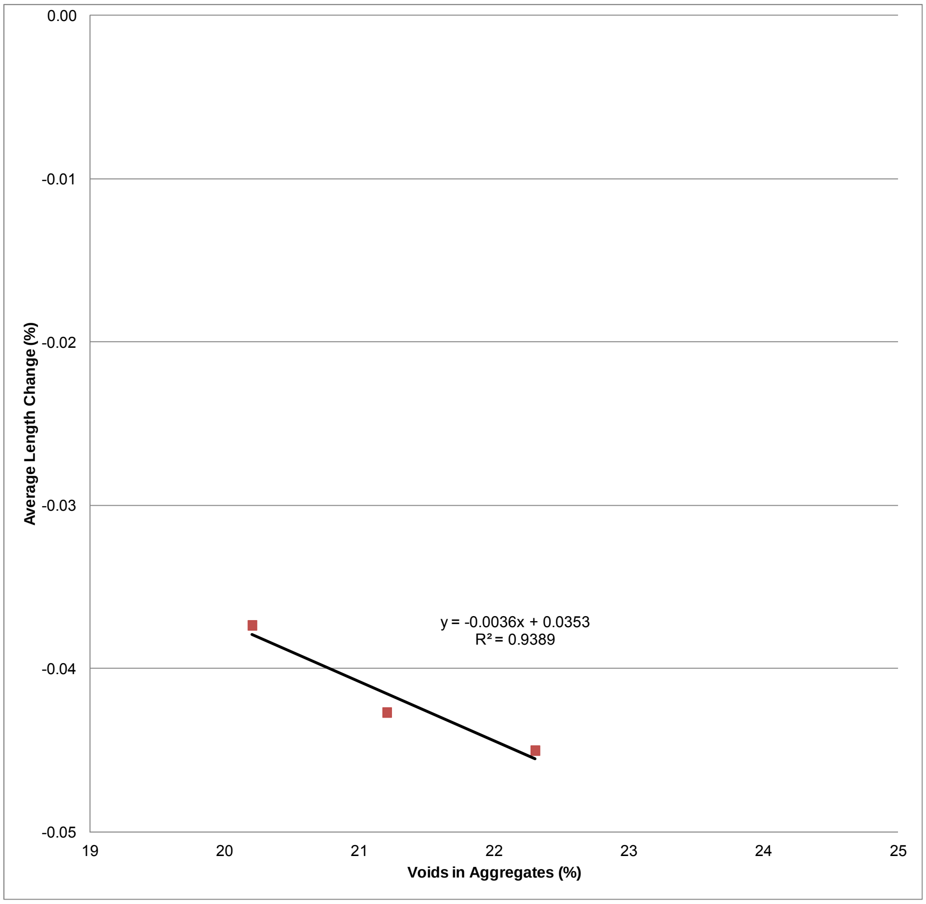

Figure 67 - Average Length Change vs Voids in Aggregates (564 PCY)

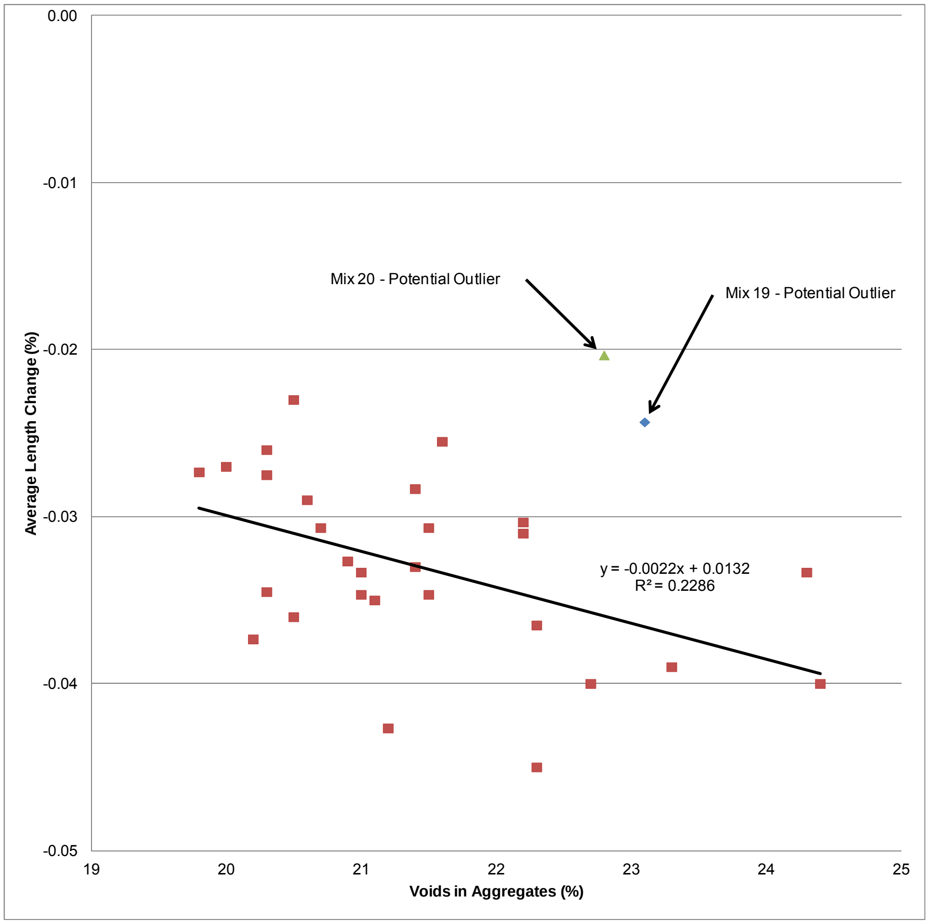

Figure 68 - Average Length Change vs Voids in Aggregates (All Mixes)

Length Change Trends Based on Cement Content

This section provides information useful for estimating the amount of length change expected when using 484.1, 526.4, and 578.1 pounds of cement per cubic yard with various aggregate gradations. Each of the mixes has a w/c ratio of 0.45 except for Mix 30. It is important to note that data included herein are based on one source of portland cement, one source of fine and coarse aggregates, and no admixtures. All of these factors will influence the rate of length change and the ultimate length change of concrete.

Regression Analysis.

Figures 69 through 71 present graphs of average percent length change for mixes with cement contents of 484.1, 526.4, and 578.1 PCY, respectively. These data were plotted and a regression analysis performed. The curve developed is defined by a polynomial equation that may be useful in predicting shrinkage for mixes with similar characteristics.

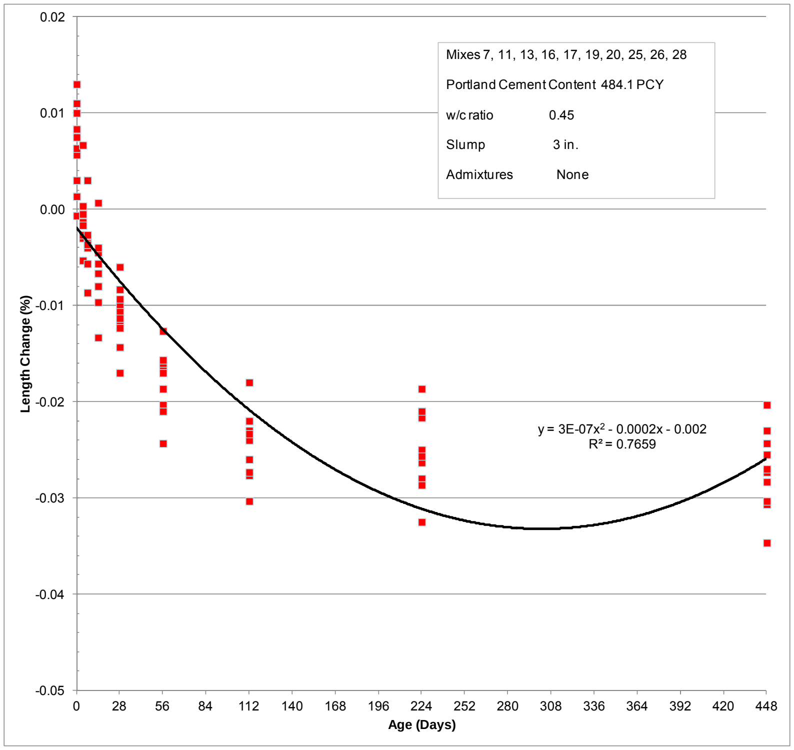

Figure 69 – Average Length Change vs Age (484.1 PCY)

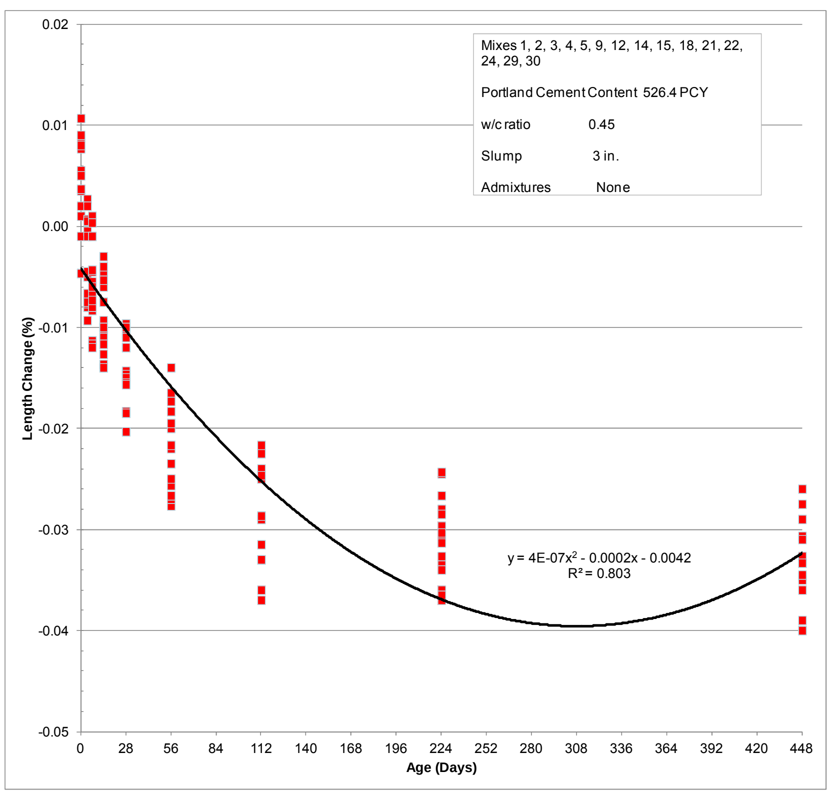

Figure 70 - Average Length Change vs Age (526.4 PCY)

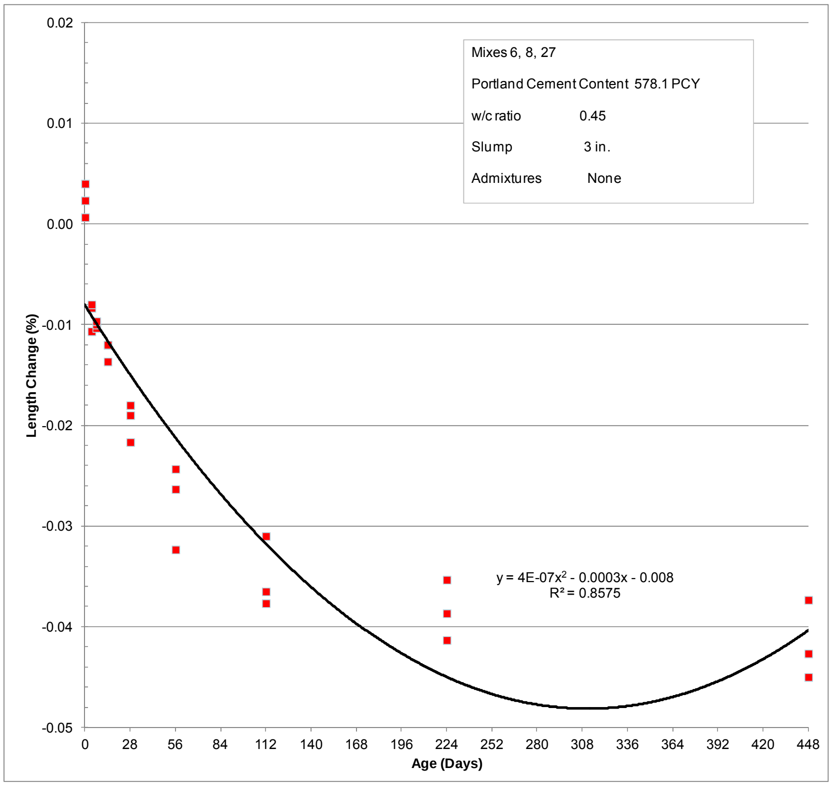

Figure 71 - Average Length Change vs Age (578.1 PCY)

Influence of Voids in Aggregates on Shrinkage.

Figures 72 through 74 present graphs of average shrinkage for all mixes containing cement contents of 484.1, 526.4, and 578.1 PCY, respectively. Regression analysis includes the maximum and minimum length changes (shrinkage) as well as the average shrinkage for these cement contents. The only difference in the mixes is the aggregate gradations. Therefore, the difference between the maximum and minimum regression lines is due to the combined aggregate gradation of each mix. Specifically, the maximum and minimum curves show the range of shrinkage percentages that can be expected from the three cement contents shown.

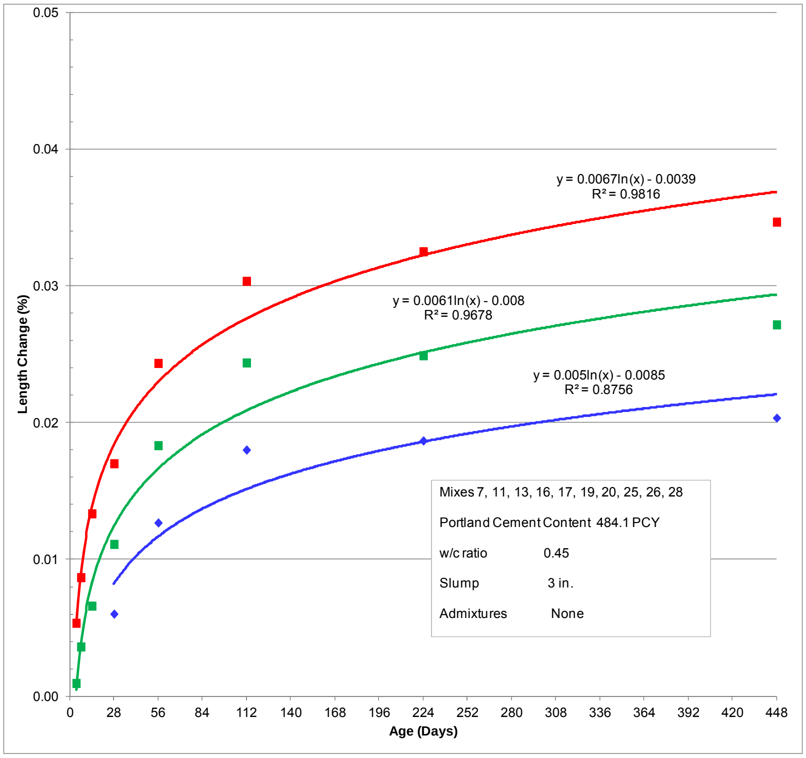

Figure 72 – Average Length Change (Shrinkage) vs Age (484.1 PCY) (Maximum, Minimum, and Average Shrinkage)

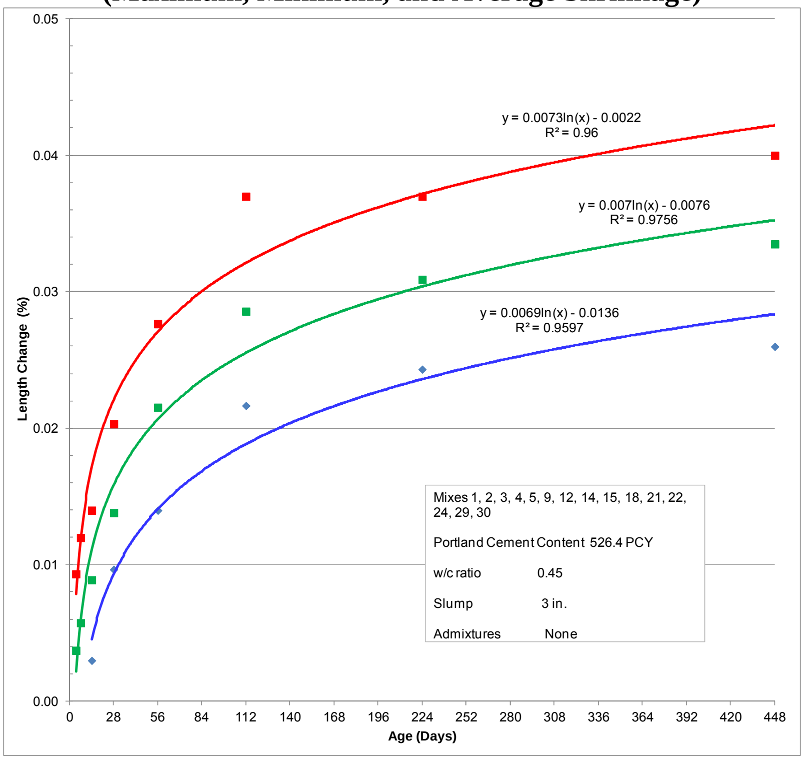

Figure 73 – Average Length Change (Shrinkage) vs Age (526.4 PCY) (Maximum, Minimum, and Average Shrinkage)

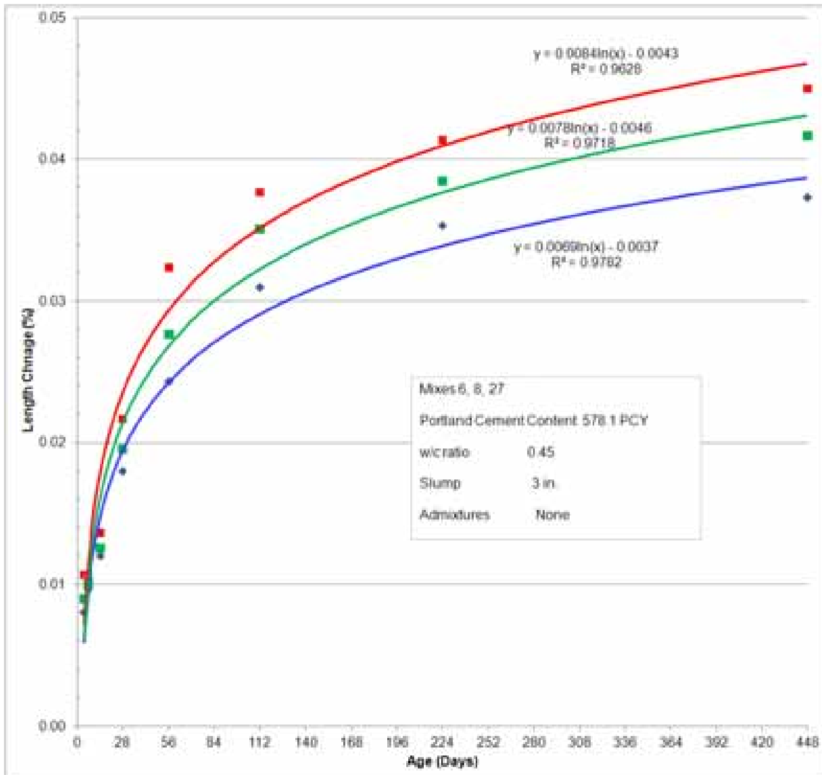

Figure 74 – Average Length Change (Shrinkage) vs Age (578.1 PCY)
(Maximum, Minimum, and Average Shrinkage)

Percentage of Ultimate Length Change

It is not practical to have to wait 476 days from the time a laboratory mixture is made until ultimate percent length change results are available for mixtures used for construction. Figures 75 through 77 can be useful in estimating the ultimate percent length change from results of specimens cured for twenty-eight days in humidity and temperature controlled room. The length change at each age was compared to the 448 day length change. The percentage of ultimate length change was then calculated and a plot was developed showing percentage of ultimate length change versus age. All readings that showed expansion during the first twenty-eight days in the humidity and temperature controlled room were omitted from these figures in order to perform regression analysis.

Trend lines along with equations were developed so percent of ultimate shrinkage can be determined at any age. Three trend lines are shown in Figures 75, 76, and 77 representing cement contents of 484.1, 526.4, and 578.1 PCY, respectfully. Maximum, minimum, and average percentage of ultimate length change are shown for each cement content.

Percent of ultimate length change at 28 days of curing in a humidity and temperature controlled room values are tabulated in Table 19. Based on these data, the average minimum percent of ultimate shrinkage at twenty-eight days in a temperature and humidity controlled room is 38 percent. This 38 percent can be multiplied by the specified ultimate shrinkage to determine the maximum shrinkage allowed at 28 days.

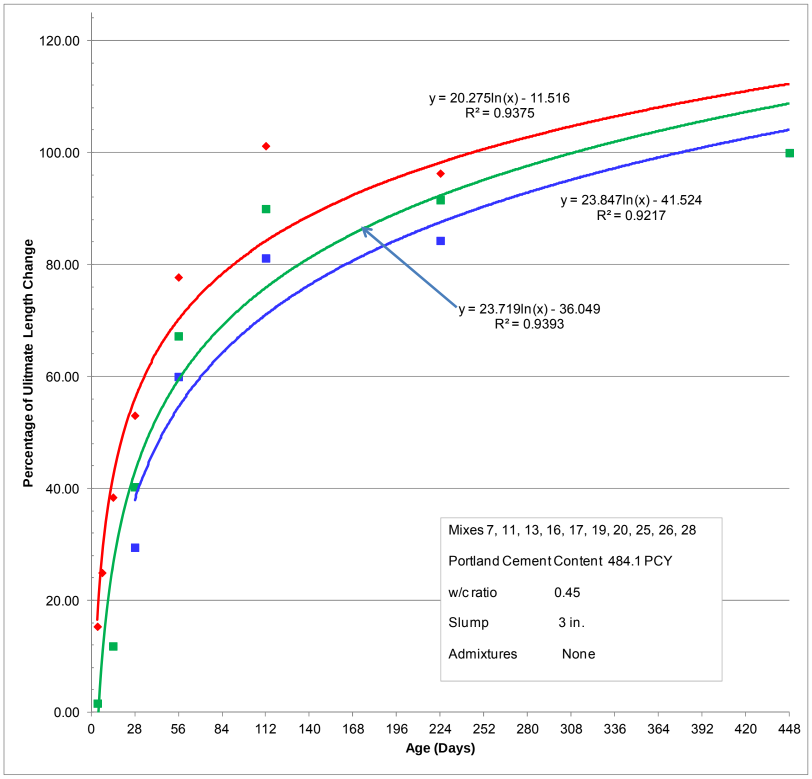

Figure 75 - Percentage of Ultimate Length Changes vs Age (484.1 PCY)

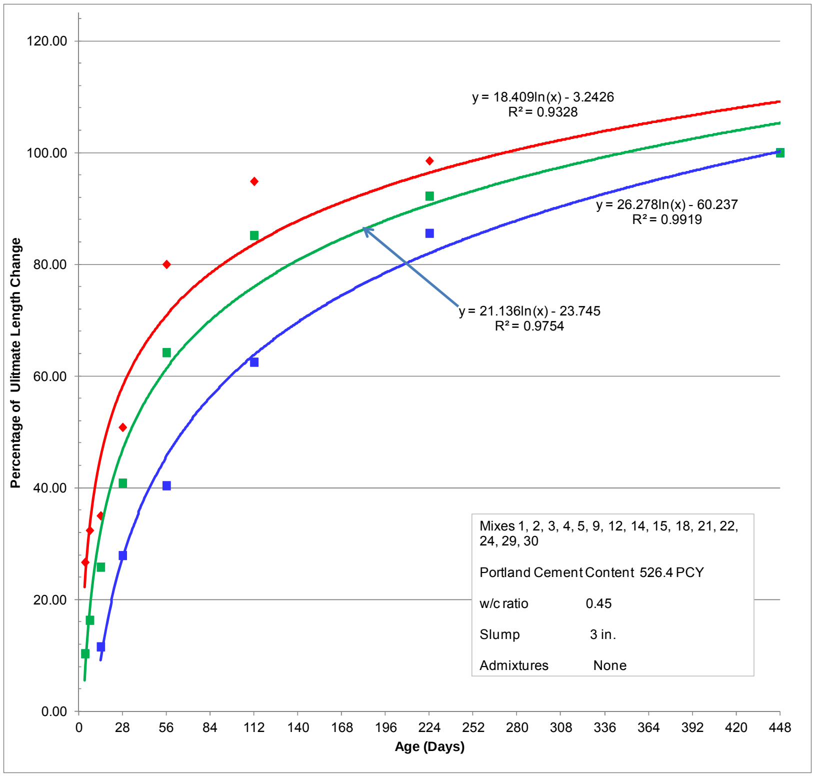

Figure 76 - Percentage of Ultimate Length Change vs Age (526.4 PCY)

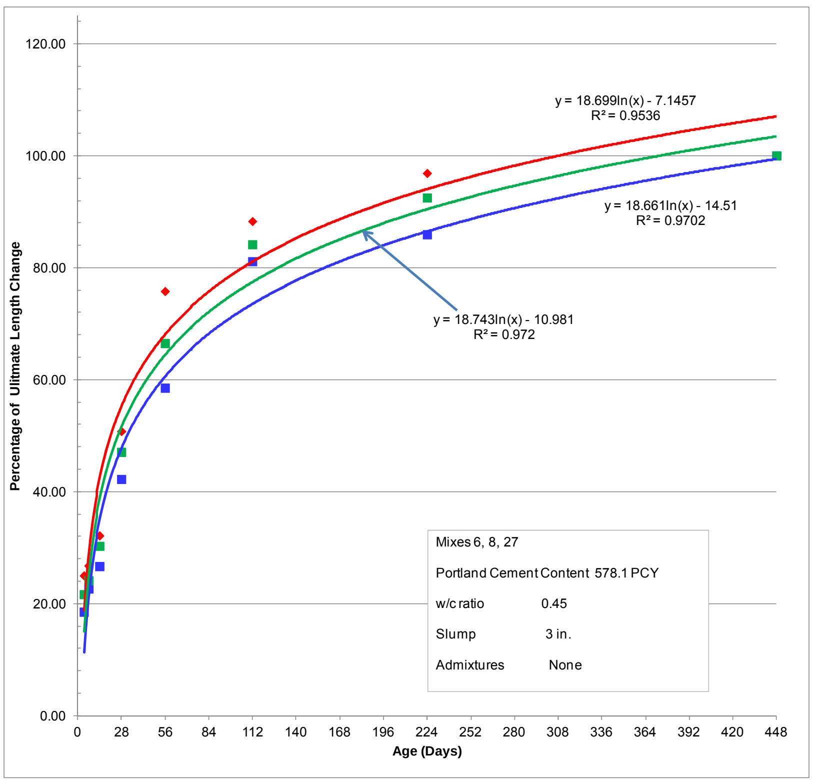

Figure 77 - Percentage of Ultimate Length Change vs Age (578.1 PCY)

Table 19 - Percent of Ultimate Length Change at 28 Days

Percentage of Ultimate Shrinkage Calculated at 28 Days in Temperate and Humidity Controlled Room	Cement Content (PCY)			Average
	484.1	526.4	578.1	
Maximum	56	58	55	56
Average	43	47	51	47
Minimum	38	27	48	38

Chapter 8 - Conclusions and Recommendations

Conclusions and recommendations are based on data sets generated from mixture proportions and materials used in this research. These data represent results from mixtures that used one source of portland cement and one source of fine and coarse aggregates and no chemical admixture. Conclusions and recommendations may not be applicable for mixtures made with any other sources of materials or other mixture proportions than those used in this study.

Conclusions

Water Demand and Cement Content.

Data in the study was used to compare performance of mixtures with combined aggregate gradations plotting in different zones of the modified coarseness factor chart. Mixtures having combined aggregate gradations with coarseness factors (CF) and adjusted workability factors (AWF) that plot in certain areas of Zones I, Zone V, and trend bar require less water to produce a given slump when compared to mixtures with CF and AWF plotting within MDOT's elliptical limits on the modified CF chart. These areas are noted in Figure 25 by mixes with cement contents that are less than 526.4 PCY. This is due to combined aggregate gradations that plot in these areas of Zone I, Zone V, and trend bar providing better workability that requires less water for a given slump. Mixtures having combined aggregate gradations with coarseness factors and adjusted workability factors that plot in Zone IV require more water to produce a given slump when compared to mixtures that plot in MDOT's elliptical limits. This is because there are too many fines associated with mixtures whose CF and AWF plot in Zone IV. If the goal of the mixture designer is to create a combined aggregate gradation that reduces that amount of water and cement required to produce a given slump, then certain areas of Zone I, V and trend bar need to be utilized.

Data in this study show that if w/c ratio remains constant, then water demand per cubic yard can increase by 23.3 PCY as CF and AWF moves from MDOT's ellipse to Zone IV. This requires an additional 51.7 pounds of cement PCY to keep the same water cement ratio. Zone IV should be avoided because of the increase in water demand due to the excessive amount of fines associated with this zone.

Data in this study show that water demand per cubic yard can be reduced by up to 19 PCY when CF and AWF moves from MDOT's elliptical limits to certain areas of Zone I, Zone V and trend bar. These areas are noted in Figure 25 by mixes with cement contents that are less than 526.4 PCY. If w/c ratio remains constant, then the cement content can be reduced by 42.3 PCY if water content is reduced by 19 PCY

Data in this study show that a reduction in cement and water can be achieved as coarseness factor and adjusted workability factor move from MDOT's elliptical limits on the CF chart to certain areas of Zone I, Zone V and trend bar. These areas are noted in Figure 25 by mixes with cement contents that are less than 526.4 PCY. In addition, data in this study show that an increase in cement and water is required as CF and AWF moves from MDOT's elliptical limits on the modified CF chart to Zone IV.

Workability Index.

A test method was developed for this study to determine the ease of which concrete can be placed, consolidated, and finished using a modified slump test. This test method produces a workability index (WI) that can be used to estimate how different mixtures will consolidate and finish under field conditions. If the goal of the concrete mixture designer is to have the highest workability index (high workability in the field), the target CF and AWF of the aggregate grading for the mixtures should plot between CF 40 and CF 50 within Zones II and III. High WI was also observed in Zone IV, but this zone should not be used because of the high water demand associated with this zone. In addition, mixes with CF and AWF plotting in certain areas of Zones I, V and trend bar can provide workability index values similar to CF and AWF plotting in MDOT's elliptical limits on the modified CF chart. These areas are noted in Figure 35 with WI in the range of 5 to 7.2 in.

Unit Weight and Voids in Aggregate.

If the goal of the concrete mixture designer is to create a combined aggregate grading that produces the least amount of void space in aggregate, rules of thumb such as the "8-18" rule may provide guide lines but do not always provide the least amount of void space between aggregate particles. Mississippi gravel aggregates were combined in this study to produce voids in aggregates that ranged from a low of 19.4 percent to a high of 24.4 percent. The 19.4 percent voids did not occur in a mix that complied with MDOT's limits for combined percent retained on individual sieves, but occurred with a combined percent retained chart that had an excess of 1 in and ½ in. material and a deficiency of No, 4, No. 8, and No. 16 when compared to MDOT's requirements.

The "hay stack" gradations of Mixes 2 and 4 met all requirements for combined percent retained on individual sieves found in ACI 302.1R section 5.4.3 and MDOT's specifications for Class BD concrete except for the amount of pan material on Mix 2. Even though combined aggregate gradations of Mixes 2 and 4 met all of these requirements, they produced mixtures with moderate to high percent voids contents in aggregate.

Compressive Strength.

All thirty mixtures had compressive strength that exceeded MDOT's requirement of 4,000 psi in 28 days for class BD concrete. In general, as the AWF increases the compressive strengths decrease because of the increased voids created by excessive fines.

Percent Length Change.

The average length change increases as paste content increases. The difference in minimum and maximum percent shrinkage shown in Table 18 can be may be attributed to the surface area of aggregate particles, entrapped air content, and void content between aggregate particles that is created by combined aggregate gradation. The maximum difference in shrinkage that can be attributed in this study to these factors is 0.0144 percent. Data in this study confirm that both paste content and combined aggregate gradation both have influence on shrinkage of concrete.

Recommendations

We recommend that MDOT consider expanding the elliptical limits of the modified CF chart to include certain areas of Zone I, Zone III, Zone V, and trend bar. Figure 78 presents a superimposed rectangle that delineates the recommend zone on the modified CF chart for 1 in. nominal maximum size Mississippi gravel aggregate gradations used for bridge deck concrete. The area of this rectangle is 420 square units of the modified CF chart and the corner coordinates of this rectangle are shown in Figure 78. The area of MDOT's elliptical limits is 163.4 square units of the modified CF chart. The recommend change in area is 256.6 square units or a 257 percent increase in size with respect to MDOT's elliptical limits.

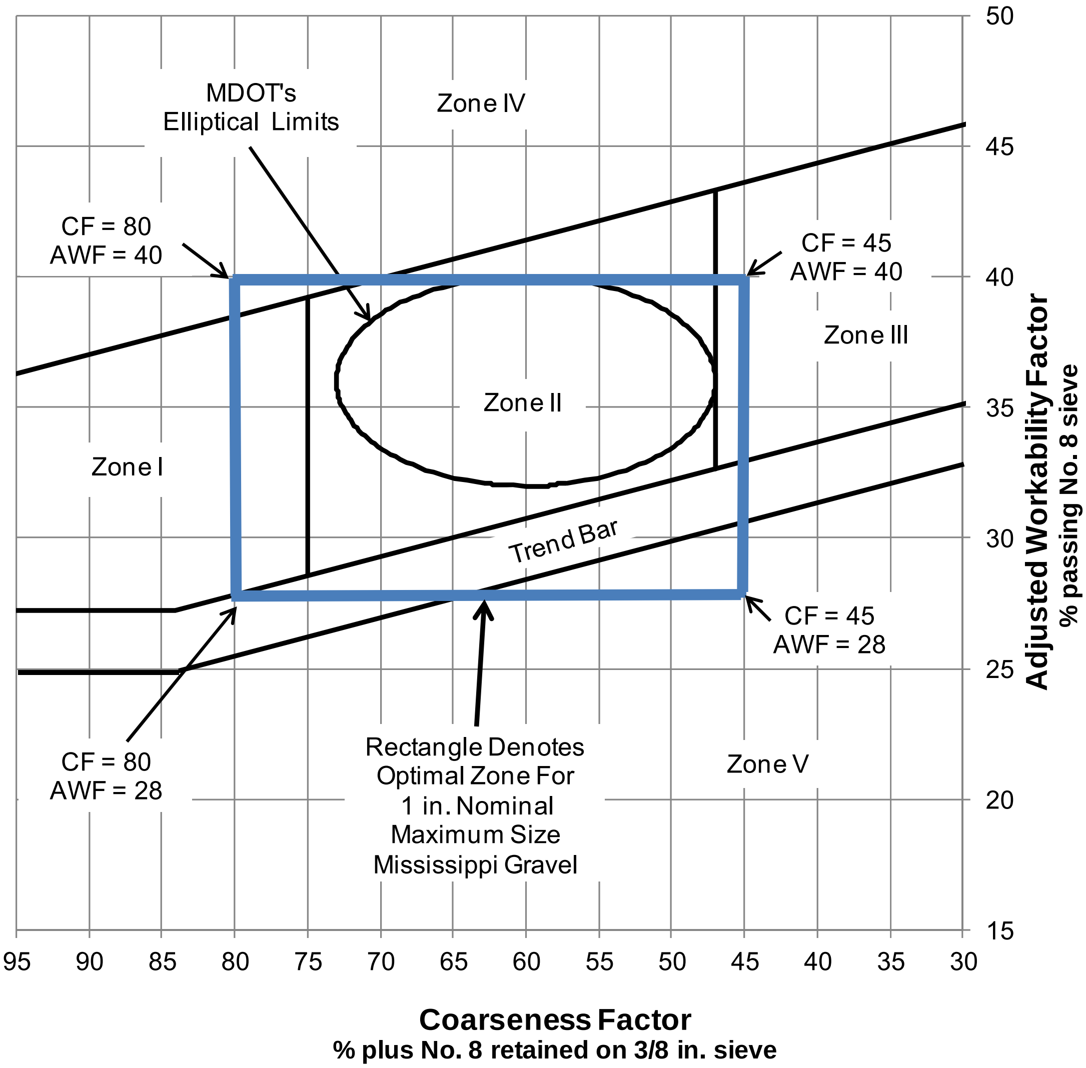

Figure 78 - Recommend Optimal Zone on the Modified Coarseness Factor Chart (1 in. Nominal Maximum Size Mississippi Gravel)

Mixes included in this study with combined aggregate gradations producing low void contents (less than 21%) may be used to set limits for percent retained on individual sieves. These limits are presented in Figure 79 and Table 20. We recommend that MDOT revise requirements for percent retained on individual sieves to the values shown in Figure 79 and Table 20. In addition, we recommend that MDOT require that the dry rodded unit weight and voids in aggregate calculations be included in mixture design submittals with a maximum value of 21 percent voids. Figures 80 and 81 are provided to show the recommended limits superimposed on percent retained on individual sieves for all mixes included in this research and MDOT's limits for percent retained on individual sieves, respectively.

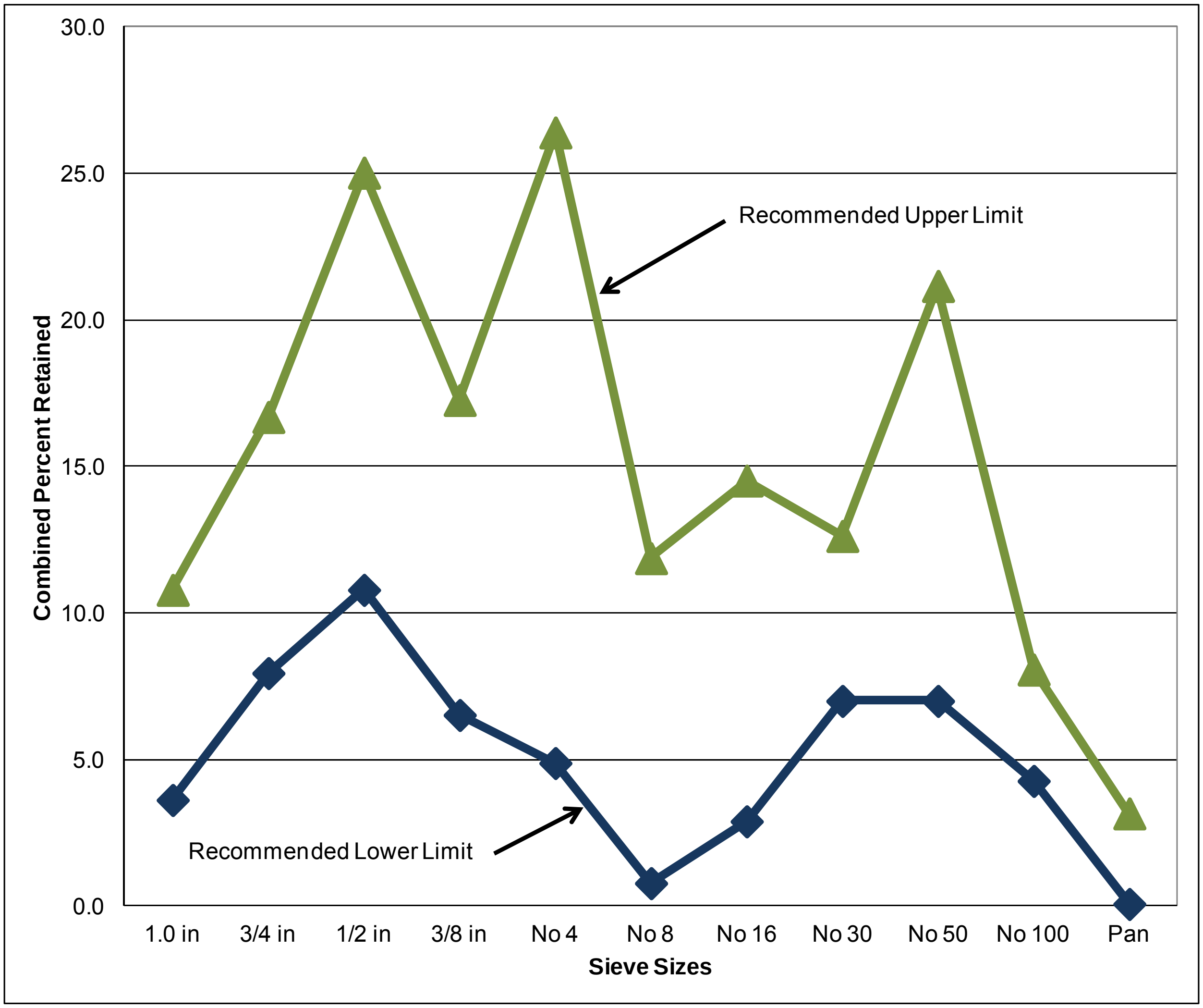

Figure 79 - Recommended Limits for Percent Retained on Individual Sieves

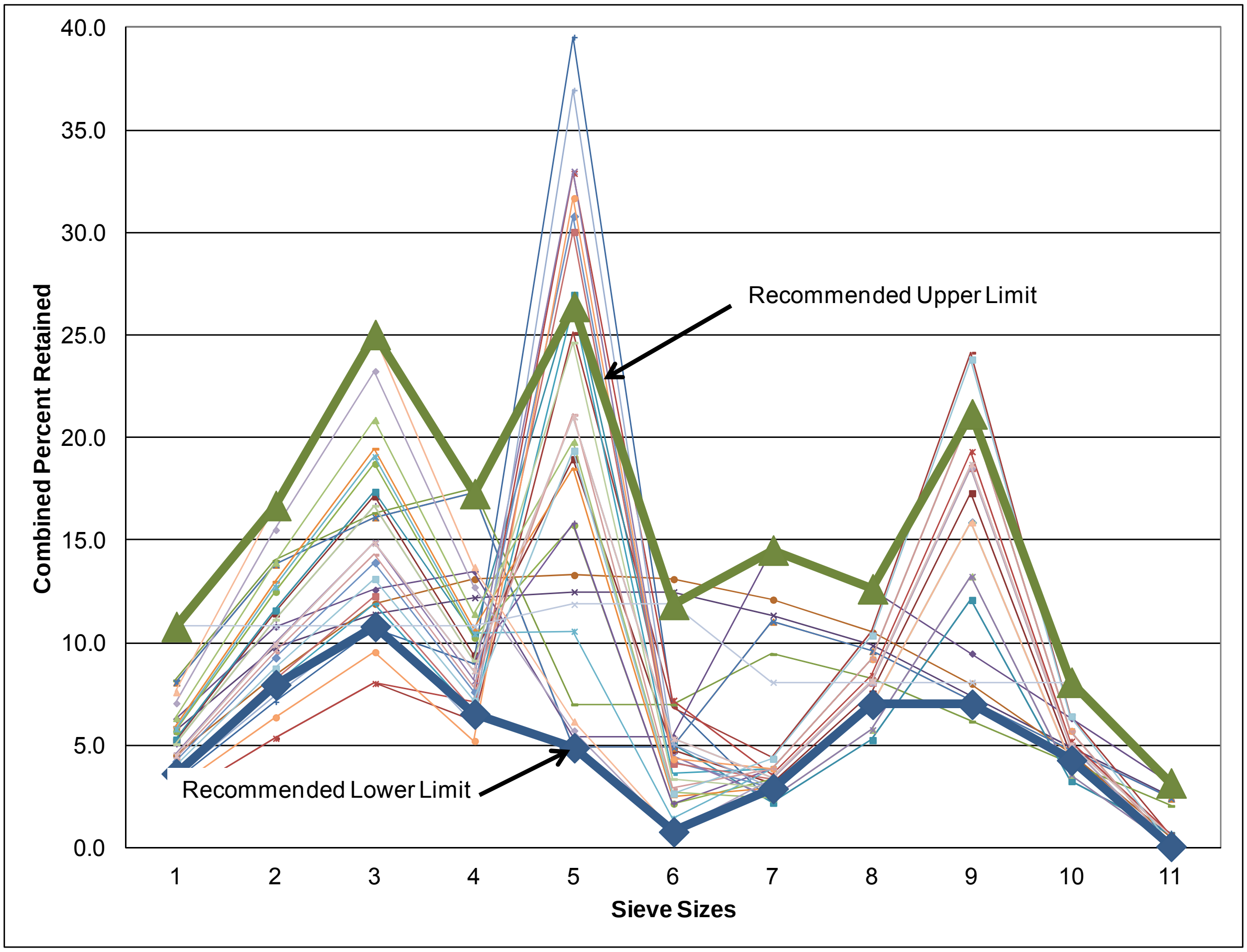

Figure 80 - Recommended Limits for Percent Retained on Individual Sieves Superimposed on Percent Retained on Individual Sieves used for Research Mixes

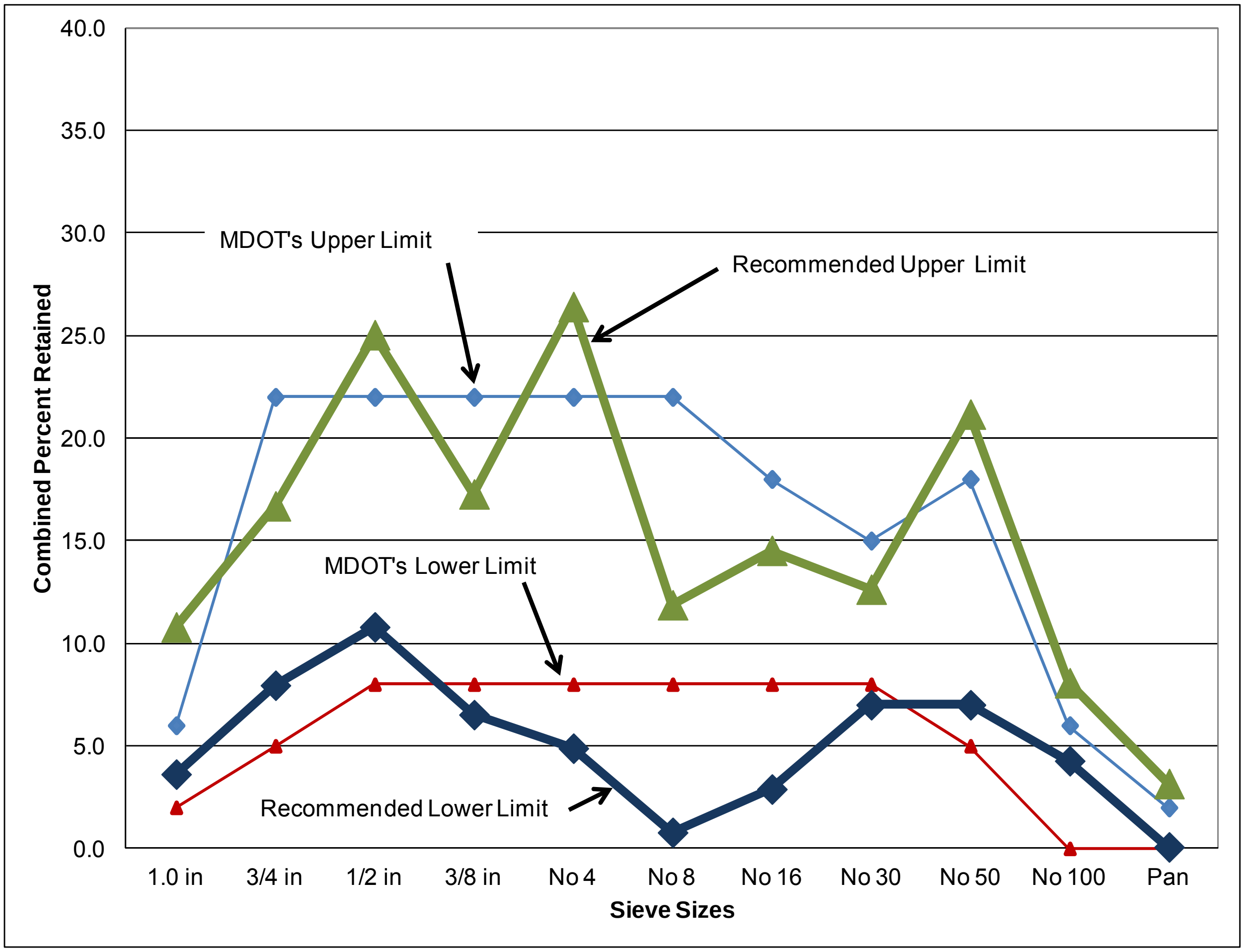

Figure 81 - Recommended Limits for Percent Retained on Individual Sieves Superimposed on MDOT's Limits for Percent Retained on Individual Sieves

Table 20 - Recommended Combined Percent Retained on Individual Sieves

	Combined Percent Retained on Individual Sieves											
MDOT	1-1/2 in.	1 in.	¾ in.	½ in.	3/8 in.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100	Pan
	0	2-6	5-22	8-22	8-22	8-22	8-22	8-18	8-15	5-18	0-6	0-2
Recommended	0	4-11	8-17	11-25	7-17	5-26	1-12	3-15	7-13	7-21	4-8	0-3

We recommend that MDOT establish an option for contractors to submit percent shrinkage data in lieu of meeting limits of the modified coarseness factor chart and the combined percent retained chart. Ultimate shrinkage values in this study, when rounded to the nearest one hundred percent, can be summarized by three percentages. These percentages are 0.02, 0.03, and 0.04 percent. We recommend that the ultimate percent shrinkage limit be set at 0.02 percent when rounded to the nearest one hundredth which represents the lowest shrinkage values determined by the research mixes of this study. We recommend that a shrinkage limit can also be established at 28 days of curing in a temperature and humidity controlled environment of 50% ± 4% relative humidity and 73 ± 3 º F with initial curing in accordance with AASHTO T 160 / ASTM C 157. The shrinkage at 28 days in the temperate and humidity controlled room should not exceed 0.01 percent when rounded to the nearest one hundredth. This 28 day shrinkage is 38 percent of the recommended ultimate shrinkage of 0.02 percent and is based on the average minimum percent of ultimate shrinkage determined in this study and presented in Table 19.

We recommend that the maximum cementitious content for MDOT Class BD concrete be reduced from 564 PCY to 526.4 PCY to reduce shrinkage. We recommend that MDOT allow contractors to choose the maximum air content for MDOT Class BD from a range of 6 to 8 percent. This range will allow the contractor to select higher air content if it is needed to improve workability or a lower air content if required to achieve desired compressive strength.

Research Opportunities

1. A research project should be conducted to validate data of this study on concrete mixtures that meet MDOT's criteria for chemical admixtures, strength, and fresh properties using various sources of gravel aggregate.
2. A research project should be conducted to determine if aggregate absorption has a significant impact on shrinkage.
3. A field study should be conducted to validate workability and pumpability of mixtures following recommendations provided in this report.

References

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Appendix A

State Study FMS 106172-101000

Curing Method Influences on Shrinkage of Gravel Aggregate Concrete

Additional testing was performed on Mix 1 to determined the influence of initial curing conditions on prism specimens used to measure length change of harden concrete. Four methods of initial curing was testing include; 1) 7 day water soak, 2) 14 day water soak, 3) 28 day water soak, and 4) curing compound. Results of this testing is included in Figure 82.

The data show that the longer the specimens cure in a water bath, the less shrinkage is to be expected. Tables 21 and 22 present a comparison of length change of each curing method and compares shrinkage with shrinkage determined from specimens cured in a water bath for 28 days.

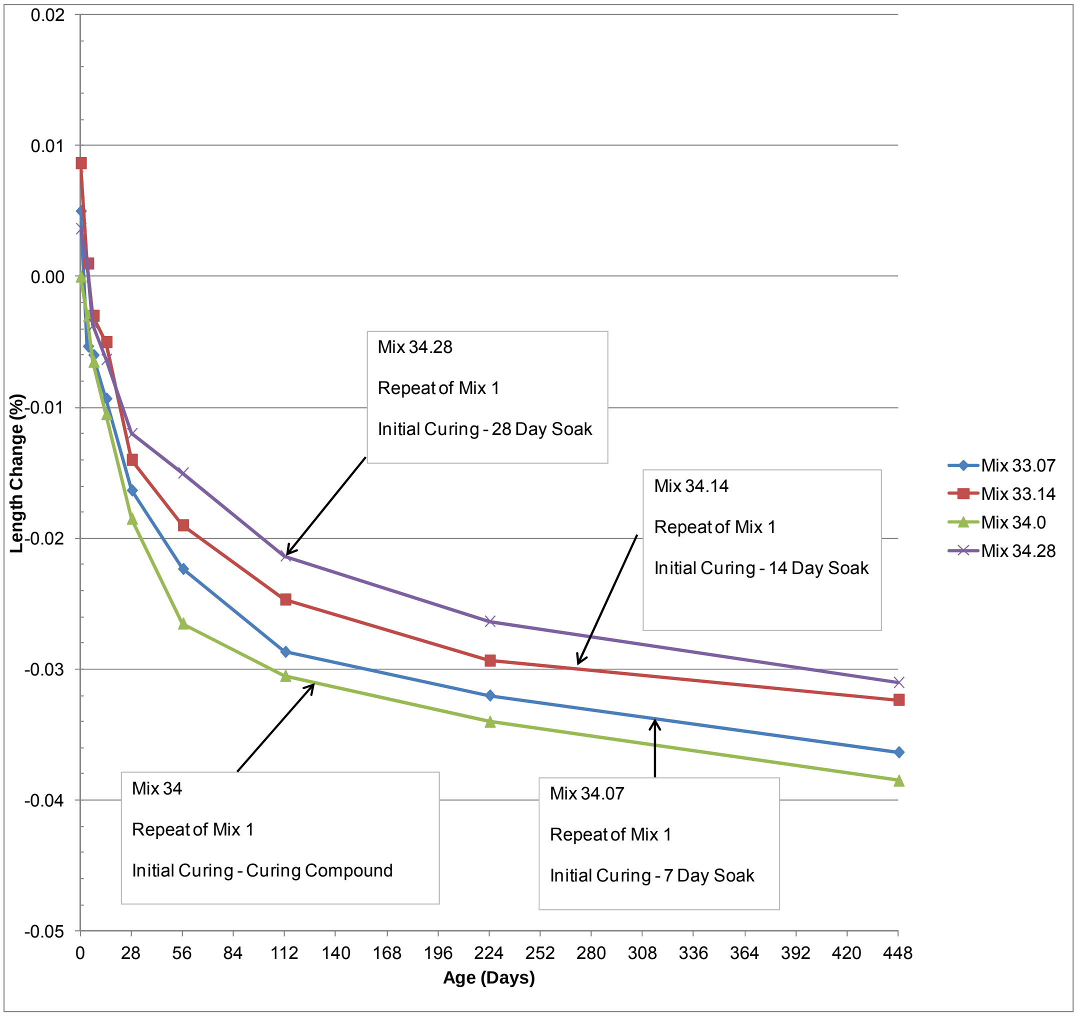


Figure 82 - Influence of Initial Curing on Length Change Specimens

Table 21 - Influence of Initial Curing - 448 Day Shrinkage

Initial Curing	448 Day Shrinkage (%)	Percent of 448 Day Shrinkage (%)
28 Day Water Soak	-0.0310	100
14 Day Water Soak	-0.0323	104
7 Day Water Soak	-0.0363	117
Curing Compound	-0.0385	124

Table 22 - Influence of Initial Curing - 28 Day Shrinkage

Initial Curing	28 Day Shrinkage (%)	Percent of 28 Day Shrinkage (%)
28 Day Water Soak	-0.0120	100
14 Day Water Soak	-0.0140	117
7 Day Water Soak	-0.0163	136
Curing Compound	-0.0185	154

Appendix B

Raw Data:

Concrete Mixtures, Length Change, Dry Rodded Unit Weight of Aggregates

Burns Cooley Dennis, Inc - State Study No. 231

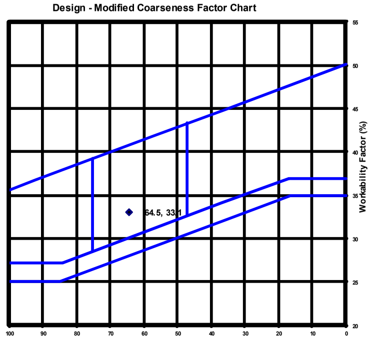
Customer:	MDOT	Project:	090594	MIX	1.0
MIX NUMBER	GC206	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	GC206

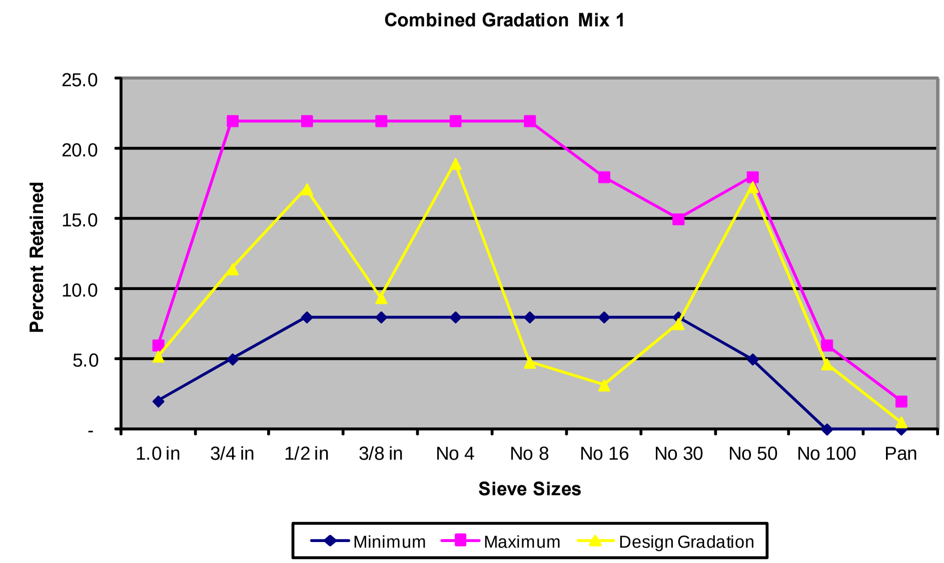
Date: 6/28/2010 | f'c: 4,000 psi | Design w/c ratio 0.450 | Size(c.f.): 1.25 | Factor: 0.05

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.5%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.1570	13.16
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	5.2000	2.5290	1.510%	3.77	-	-1.510%	-0.11	1.0320	162.8990	7.5420	7.5420	7.57
3/4 in	5.0	22.0	11.4300	2.5290	1.510%	8.29	-	-1.510%	-0.25	2.2690	358.0650	16.5770	16.5770	16.56
1/2 in	8.0	22.0	17.1400	2.5290	1.510%	12.43	-	-1.510%	-0.38	3.4020	536.9410	24.8580	24.8580	24.85
3/8 in	8.0	22.0	9.3700	2.5290	1.510%	6.79	-	-1.510%	-0.21	1.8600	293.5320	13.5890	13.5890	13.59
No 4	8.0	22.0	18.9500	2.5290	1.510%	13.74	-	-1.510%	-0.41	3.7620	593.6430	27.4830	27.4830	27.49
No 8	8.0	22.0	4.7700	2.5290	1.510%	3.46	-	-1.510%	-0.10	0.9470	149.4290	6.9180	6.9180	6.91
No 16	8.0	18.0	3.1500	2.5290	1.510%	2.28	-	-1.510%	-0.07	0.6250	98.6790	4.5680	4.5680	4.57
No 30	8.0	15.0	7.5200	2.5290	1.510%	5.45	-	-1.510%	-0.16	1.4930	235.5770	10.9060	10.9060	10.91
No 50	5.0	18.0	17.2900	2.5290	1.510%	12.54	-	-1.510%	-0.38	3.4320	541.6400	25.0760	25.0760	25.08
No 100	-	6.0	4.6500	2.5290	1.510%	3.37	-	-1.510%	-0.10	0.9230	145.6700	6.7440	6.7440	6.74
Pan	-	2.0	0.5200	2.5290	1.510%	0.38	-	-1.510%	-0.01	0.1030	16.2900	0.7540	0.7540	0.76
Total Grad%			100.0			72.51			-2.19	26.9970	3895.6450	180.3520	182.5420	182.5600

	Min	Max	Design
Fineness Mod			0.77
Q	22.0	72.0	43.1
I	16.0	44.0	23.7
W	21.0	64.0	33.1
CF Actual	57.7	64.3	64.5
WF Actual			33.1
AWF	23.0	49.0	32.13

Design - Modified Coarseness Factor Chart





Plastic Test Results

Batch Time	11:15 AM	% Air	2.75	Unit Wt w/o Air	148.00	Design w/c	0.450
Sample Time	11:23 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.20	Actual w/c	0.450
Air Temp.	77.0	Bucket Full	41.95	Theorectial Air	1.22	Design Unit Wt	144.30
Mix Temp.	80.1	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.50
Slump, in.	3.25	Paste Volume (%)	24.01	Relative Yield	1.00	Bag Factor	5.60

Comments / Notes / Observations

Typical Paving Mix - 72% DRUW CA Content

Mix Percent by Weight

No. 57	64.20
No. 8	0.00
Sand	35.80
Combined Gravity Dry	2.5290
Combined Absorption	1.5100

Workability Measurements

Workability Index	6.5	inches
Pre Vib Slump	3.75	inches
Post Vib.Slump	6.25	inches
Spread Length	14.50	inches
Spread Width	13.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/29/10	1	2390	2435
	1	2480	
07/05/10	7	4540	4680
	7	4820	
07/12/10	14	4680	4700
	14	4720	
07/26/10	28	4900	5120
	28	5200	
	28	5260	
08/23/10	56	5110	5345
	56	5580	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/10/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 1.0
Mix Date Monday, June 28, 2010 Mix Time: 11:15 AM

Measurements Required Before Making Specimens

Specimen	Nominal Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8145	11.65700	1.6290	10.0280
2	10.0000	0.8135	0.8145	11.63445	1.6280	10.0065
3	10.0000	0.8135	0.8155	11.55945	1.6290	9.9305

SHRINKAGE TESTING - ASTM C157

INITIAL READINGS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
	Gage Length (in.): 10	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Tuesday, June 29, 2010	**0.0740**	**0.0344**	0.0396	**0.0477**	**0.0344**	0.0133			No record	0.0265	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Monday, July 26, 2010	**0.1405**	**0.1000**	0.0090	**0.1135**	**0.1000**	0.0020			No record	0.0055	**Soak**
32	Friday, July 30, 2010	**0.1399**	**0.1004**	-0.0010	**0.1128**	**0.1004**	-0.0090			No record	-0.0050	**Shrinkage Room**
35	Monday, August 02, 2010	**0.1395**	**0.1001**	-0.0020	**0.1125**	**0.1001**	-0.0090			No record	-0.0055	
42	Monday, August 09, 2010	**0.1392**	**0.1001**	-0.0050	**0.1124**	**0.1001**	-0.0100			No record	-0.0075	
56	Monday, August 23, 2010	**0.1389**	**0.1001**	-0.0080	**0.1118**	**0.1001**	-0.0160			No record	-0.0120	
84	Monday, September 20, 2010	**0.1380**	**0.0996**	-0.0120	**0.1108**	**0.0996**	-0.0210			No record	-0.0165	
140	Monday, November 15, 2010	**0.1389**	**0.1013**	-0.0200	**0.1121**	**0.1013**	-0.0250			No record	-0.0225	
252	Monday, March 07, 2011	**0.1377**	**0.1001**	-0.0200	**0.1105**	**0.1001**	-0.0290			No record	-0.0245	
479	Thursday, October 20, 2011	**0.1381**	**0.1008**	-0.0230	**0.1109**	**0.1008**	-0.0320			No record	-0.0275	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 06/28/10

Material: Mix 1.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**79.18**	**78.88**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**125.810**	**125.210**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**125.510**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5290**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.3**	

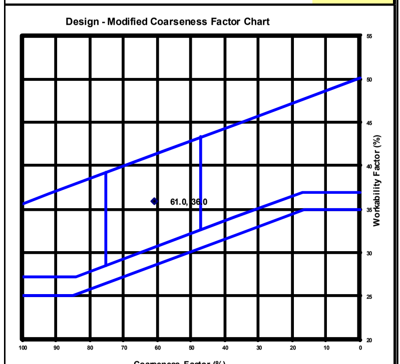
Reviewed By: Robert Varner, P.E. 7/9/2010

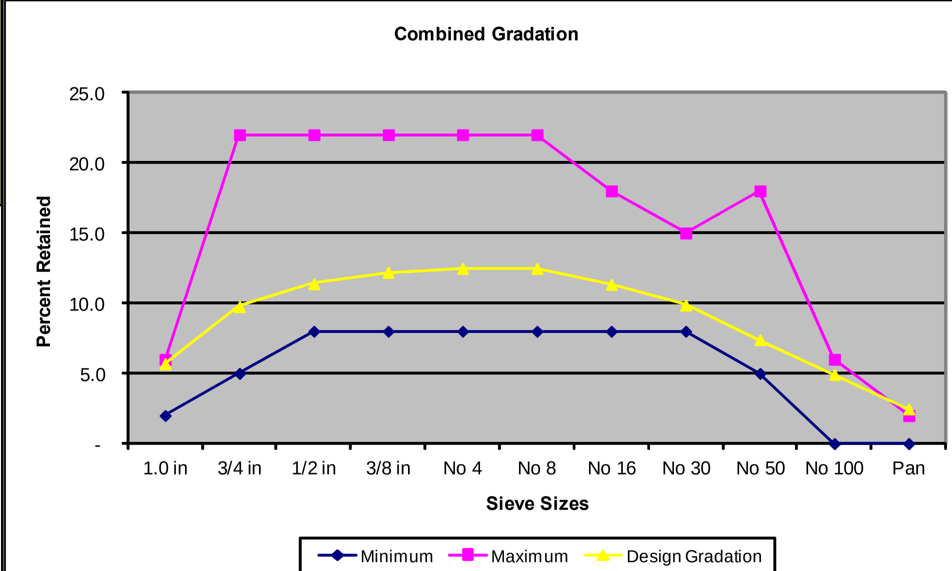
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT
Project:	090594
MIX	2.0
MIX NUMBER	MM01
Notes:	Optimizing MS Aggregates for Concrete Bridge Decks
Set #:	MM01
Date:	6/29/2010
f'c:	4,000 psi
Design w/c ratio	0.450
Size(c.f.):	1.25
Factor:	0.05

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.5%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.1560	13.16
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	5.6900	2.4770	2.200%	4.04	-	-2.200%	-0.18	1.1300	174.5840	8.0830	8.0830	8.09
3/4 in	5.0	22.0	9.7600	2.4770	2.200%	6.93	-	-2.200%	-0.31	1.9370	299.4630	13.8640	13.8640	13.86
1/2 in	8.0	22.0	11.3900	2.4770	2.200%	8.09	-	-2.200%	-0.36	2.2610	349.4750	16.1790	16.1790	16.18
3/8 in	8.0	22.0	12.2000	2.4770	2.200%	8.66	-	-2.200%	-0.38	2.4220	374.3280	17.3300	17.3300	17.33
No 4	8.0	22.0	12.4800	2.4880	2.200%	8.90	-	-2.200%	-0.39	2.4770	384.6200	17.8060	17.8060	17.81
No 8	8.0	22.0	12.4800	2.4880	2.200%	8.90	-	-2.200%	-0.39	2.4770	384.6200	17.8060	17.8060	17.81
No 16	8.0	18.0	11.3400	2.6280	0.260%	8.55	-	-0.260%	-0.04	2.2510	369.1520	17.0900	17.0900	17.1
No 30	8.0	15.0	9.8600	2.6280	0.260%	7.43	-	-0.260%	-0.04	1.9570	320.9740	14.8600	14.8600	14.86
No 50	5.0	18.0	7.4000	2.6280	0.260%	5.58	-	-0.260%	-0.03	1.4690	240.8930	11.1520	11.1520	11.15
No 100	-	6.0	4.9300	2.6280	0.260%	3.71	-	-0.260%	-0.02	0.9790	160.4870	7.4300	7.4300	7.43
Pan	-	2.0	2.4700	2.5320	1.500%	1.79	-	-1.500%	-0.05	0.4900	77.4690	3.5870	3.5870	3.59
Total Grad%			100.0			72.59			-2.19	26.9990	3899.3450	180.5240	182.7130	182.7400

Fineness Mod			0.80
Q	22.0	72.0	39.0
I	16.0	44.0	25.0
W	21.0	64.0	36.0
CF Actual	48.4	73.6	61.0
WF Actual			36.0
AWF	23.0	49.0	35.00





Comments / Notes / Observations

Graphically Optimized Grading

Mix Percent by Weight	
No. 57	39.00
No. 8	25.00
Sand	36.00
Combined Gravity Dry	2.5320
Combined Absorption	1.5000

Workability Measurements		
Workability Index	6.5	inches
Pre Vib Slump	3.75	inches
Post Vib.Slump	6.25	inches
Spread Length	14.50	inches
Spread Width	13.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
06/30/10	1	2520	2435
	1	2350	
07/06/10	7	4660	4875
	7	5090	
07/13/10	14	5170	4970
	14	4770	
07/27/10	28	5810	5530
	28	5700	
	28	5080	
08/24/10	56	6190	6130
	56	6070	

Technician who conducted tests:

Plastic Test Results

Batch Time	2:27 PM	% Air	3.0	Unit Wt w/o Air	148.13	Design w/c	0.450
Sample Time	2:36 PM	Bucket Weight	5.40	Unit Wt (pcf)	145.20	Actual w/c	0.450
Air Temp.	75.1	Bucket Full	41.7	Theorectial Air	1.98	Design Unit Wt	144.43
Mix Temp.	74.8	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.59
Slump, in.	3.25	Paste Volume (%)	23.82	Relative Yield	1.01	Bag Factor	5.60

Reviewed by: Robert Varner, P.E. 7/10/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 2.0
Mix Date: Tuesday, June 29, 2010 Mix Time: 2:27 PM

Measurements Required Before Making Specimens

Specimen	Nominal Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8170	0.8130	11.64265	1.6300	10.0127
2	10.0000	0.8140	0.8140	11.61250	1.6280	9.9845
3	10.0000	0.8120	0.8150	11.62350	1.6270	9.9965

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
Specimen Age	Test date	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Wednesday, June 30, 2010	**0.0573**	**0.0345**	0.0228	**0.0255**	**0.0345**	-0.0090	**0.0356**	**0.0345**	0.0011	0.0050	M/Rm
		LENGTH CHANGE CALCULATIONS										
		Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	Soak
28	Tuesday, July 27, 2010	**0.1236**	**0.1003**	0.0050	**0.0914**	**0.1003**	0.0010	**0.1019**	**0.1003**	0.0050	0.0037	Soak
32	Saturday, July 31, 2010	**0.1228**	**0.1004**	-0.0040	**0.0908**	**0.1004**	-0.0060	**0.1011**	**0.1004**	-0.0040	-0.0047	Shrinkage Room
35	Tuesday, August 03, 2010	**0.1225**	**0.1003**	-0.0060	**0.0905**	**0.1003**	-0.0080	**0.1008**	**0.1003**	-0.0060	-0.0067	Shrinkage Room
42	Tuesday, August 10, 2010	**0.1223**	**0.1004**	-0.0090	**0.0903**	**0.1003**	-0.0100	**0.1005**	**0.1003**	-0.0090	-0.0093	Shrinkage Room
56	Tuesday, August 24, 2010	**0.1221**	**0.1002**	-0.0090	**0.0901**	**0.1002**	-0.0110	**0.1004**	**0.1002**	-0.0090	-0.0097	Shrinkage Room
84	Tuesday, September 21, 2010	**0.1216**	**0.1001**	-0.0130	**0.0896**	**0.1001**	-0.0150	**0.0998**	**0.1001**	-0.0140	-0.0140	Shrinkage Room
140	Tuesday, November 16, 2010	**0.1206**	**0.0999**	-0.0210	**0.0886**	**0.0999**	-0.0230	**0.0989**	**0.0999**	-0.0210	-0.0217	Shrinkage Room
252	Tuesday, March 08, 2011	**0.1211**	**0.1013**	-0.0300	**0.0894**	**0.1013**	-0.0290	**0.0994**	**0.1013**	-0.0300	-0.0297	Shrinkage Room
478	Thursday, October 20, 2011	**0.1201**	**0.1008**	-0.0350	**0.0884**	**0.1009**	-0.0350	**0.0987**	**0.1010**	-0.0340	-0.0347	Shrinkage Room

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 06/29/10

Material: Mix 2.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.11**	**78.27**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.670**	**123.990**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.830**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5320**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.5**	

Reviewed By: Robert Varner, P.E.

Burns Cooley Dennis, Inc - State Study No. 231

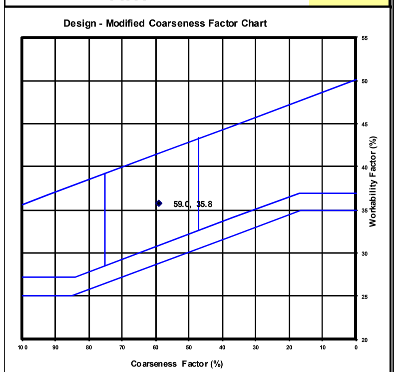
Customer: **MDOT** | Project: **090594** | MIX **3.0**

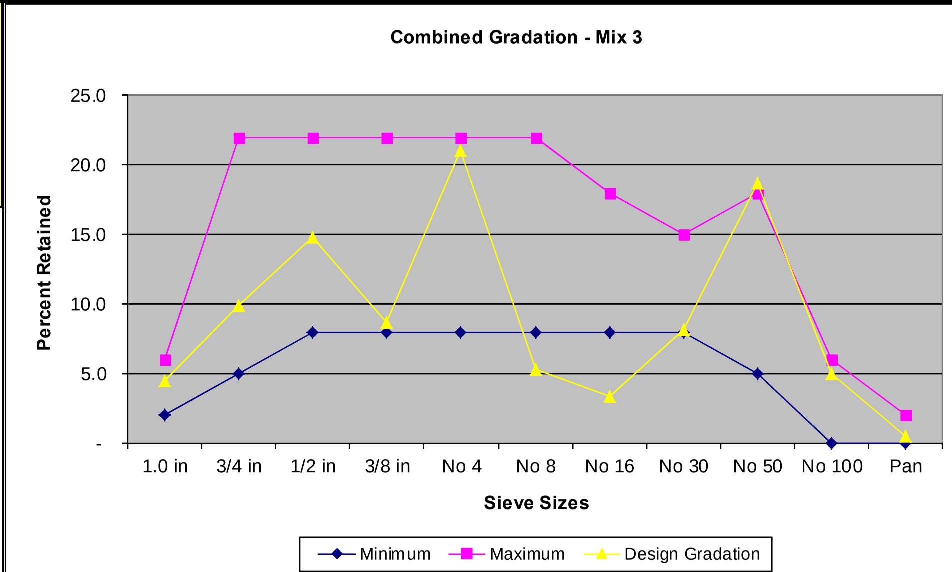
MIX NUMBER GC205 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: GC205

MIX DESIGN INFO | Date: 6/30/2010 | f'c: 4,000 psi | Design w/c ratio 0.450 | Size(c.f.): 1.25 | Factor: 0.05

Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.5%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0740	13.07
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	4.5000	2.5340	1.450%	3.27	-	-1.450%	-0.09	0.8930	141.2490	6.5390	6.5390	6.54
3/4 in	5.0	22.0	9.9000	2.5340	1.450%	7.19	-	-1.450%	-0.21	1.9650	310.7480	14.3860	14.3860	14.40
1/2 in	8.0	22.0	14.8500	2.5340	1.450%	10.79	-	-1.450%	-0.31	2.9480	466.1220	21.5800	21.5800	21.58
3/8 in	8.0	22.0	8.6300	2.5340	1.450%	6.27	-	-1.450%	-0.18	1.7130	270.8850	12.5410	12.5410	12.54
No 4	8.0	22.0	21.0200	2.5340	1.450%	15.27	-	-1.450%	-0.44	4.1730	659.7910	30.5460	30.5460	30.55
No 8	8.0	22.0	5.3100	2.5340	1.450%	3.86	-	-1.450%	-0.11	1.0540	166.6740	7.7160	7.7160	7.72
No 16	8.0	18.0	3.4100	2.5340	1.450%	2.48	-	-1.450%	-0.07	0.6770	107.0360	4.9550	4.9550	4.96
No 30	8.0	15.0	8.1300	2.5340	1.450%	5.91	-	-1.450%	-0.17	1.6140	255.1900	11.8140	11.8140	11.81
No 50	5.0	18.0	18.6900	2.5340	1.450%	13.58	-	-1.450%	-0.39	3.7100	586.6550	27.1600	27.1600	27.16
No 100	-	6.0	5.0300	2.5340	1.450%	3.65	-	-1.450%	-0.11	0.9990	157.8850	7.3090	7.3090	7.31
Pan	-	2.0	0.5300	2.5340	1.450%	0.39	-	-1.450%	-0.01	0.1050	16.6360	0.7700	0.7700	0.77
Total Grad%			100.0			72.66			-2.11	27.0000	3902.1510	180.6530	182.7600	182.7800

Fineness Mod			0.80
Q	22.0	72.0	37.9
I	16.0	44.0	26.3
W	21.0	64.0	35.8
CF Actual	48.6	73.4	59.0
WF Actual			35.8
AWF	23.0	49.0	34.79





Plastic Test Results

Batch Time	1:25 PM	% Air	3.0	Unit Wt w/o Air	148.23	Design w/c	0.450
Sample Time	1:34 PM	Bucket Weight	5.40	Unit Wt (pcf)	145.60	Actual w/c	0.450
Air Temp.	75.5	Bucket Full	41.8	Theorectial Air	1.77	Design Unit Wt	144.52
Mix Temp.	74.5	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.56
Slump, in.	3.25	Paste Volume (%)	23.87	Relative Yield	1.00	Bag Factor	5.60

Comments / Notes / Observations

KU Optimized Blend

Mix Percent by Weight

No. 57	55.60
No. 8	5.70
Sand	38.70
Combined Gravity Dry	2.5340
Combined Absorption	1.4500

Workability Measurements

Workability Index	5.0	inches
Pre Vib Slump	2.25	inches
Post Vib.Slump	4.75	inches
Spread Length	14.00	inches
Spread Width	10.75	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/01/10	1	2230	2290
	1	2350	
07/07/10	7	4760	4640
	7	4520	
07/14/10	14	5010	5185
	14	5360	
07/28/10	28	5390	5393
	28	5540	
	28	5250	
08/25/10	56	6030	5960
	56	5890	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/20/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 3.0
Mix Date: Wednesday, June 30, 2010 Mix Time: 1:25 PM

Measurements Required Before Making Specimens

Specimen	Nominal Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8170	0.8130	11.61100	1.6300	9.9810
2	10.0000	0.8130	0.8155	11.64030	1.6285	10.0118
3	10.0000	0.8145	0.8150	11.60310	1.6295	9.9736

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Thursday, July 01, 2010	**0.0215**	**0.0344**	-0.0129	**0.0509**	**0.0344**	0.0165	**0.0135**	**0.0344**	-0.0209	-0.0058	M/Rm

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Wednesday, July 28, 2010	**0.0876**	**0.1004**	0.0010	**0.1163**	**0.1004**	-0.0060	**0.0786**	**0.1004**	-0.0090	-0.0047	Soak
32	Sunday, August 01, 2010	**0.0869**	**0.1004**	-0.0060	**0.1160**	**0.1004**	-0.0090	**0.0782**	**0.1004**	-0.0130	-0.0093	Shrinkage Room
35	Wednesday, August 04, 2010	**0.0866**	**0.1003**	-0.0080	**0.1157**	**0.1003**	-0.0110	**0.0779**	**0.1003**	-0.0150	-0.0113	Shrinkage Room
42	Wednesday, August 11, 2010	**0.0866**	**0.1002**	-0.0070	**0.1156**	**0.1002**	-0.0110	**0.0779**	**0.1002**	-0.0140	-0.0107	Shrinkage Room
56	Wednesday, August 25, 2010	**0.0861**	**0.1001**	-0.0110	**0.1152**	**0.1001**	-0.0140	**0.0774**	**0.1001**	-0.0180	-0.0143	Shrinkage Room
84	Wednesday, September 22, 2010	**0.0850**	**0.0998**	-0.0190	**0.1141**	**0.0998**	-0.0220	**0.0764**	**0.0998**	-0.0250	-0.0220	Shrinkage Room
140	Wednesday, November 17, 2010	**0.0845**	**0.1013**	Erratic	**0.1137**	**0.1013**	Erratic	**0.0771**	**0.1013**	-0.0330	-0.0330	Shrinkage Room
252	Wednesday, March 09, 2011	**0.0843**	**0.1001**	-0.0290	**0.1139**	**0.1001**	-0.0270	**0.0756**	**0.1001**	-0.0360	-0.0307	Shrinkage Room
476	Wednesday, October 19, 2011	**0.0848**	**0.1010**	-0.0330	**0.1144**	**0.1010**	-0.0310	**0.0760**	**0.1010**	-0.0410	-0.0350	Shrinkage Room

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 06/30/10

Material: Mix 3.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.59**	**78.59**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.630**	**124.630**

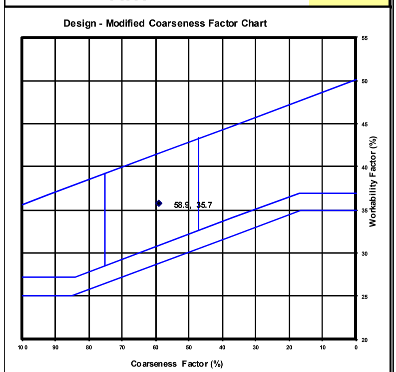
Void Content	
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.630**
Bulk Dry Specific Gravity of Aggregate, S	**2.5340**
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**
Void Content, % = 100[(S*W)-M]/(S*W)	**21.1**

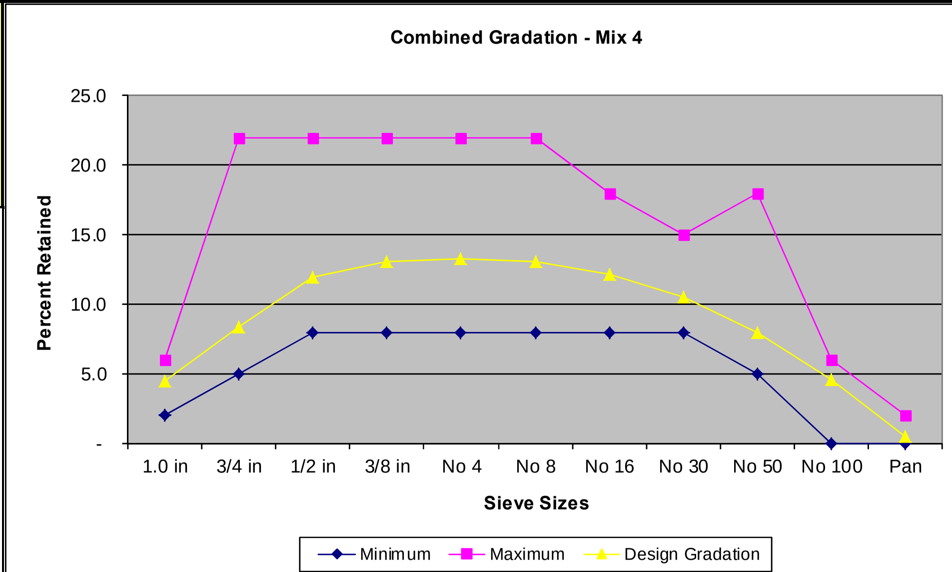
Reviewed By: Robert Varner, P.E. 7/20/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:		MDOT	Project:	090594								MIX	4.0
MIX NUMBER	GC204	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks									Set #:	GC204
MIX DESIGN INFO	Date:	7/1/2010	f'c:	4,000 psi		Design w/c ratio	0.450		Size(c.f.):	1.25		Factor:	0.05
Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.5%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.1290	13.13
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	4.5000	2.4770	2.200%	3.20	-	-2.200%	-0.14	0.8930	138.0720	6.3920	6.3920	6.39
3/4 in	5.0	22.0	8.4000	2.4770	2.200%	5.97	-	-2.200%	-0.26	1.6670	257.7340	11.9320	11.9320	11.94
1/2 in	8.0	22.0	11.9000	2.4770	2.200%	8.45	-	-2.200%	-0.37	2.3620	365.1240	16.9040	16.9040	16.9
3/8 in	8.0	22.0	13.1000	2.4770	2.200%	9.30	-	-2.200%	-0.41	2.6000	401.9430	18.6080	18.6080	18.6
No 4	8.0	22.0	13.3000	2.4880	2.200%	9.49	-	-2.200%	-0.42	2.6400	409.8920	18.9760	18.9760	18.98
No 8	8.0	22.0	13.1000	2.4880	2.200%	9.35	-	-2.200%	-0.41	2.6000	403.7280	18.6910	18.6910	18.69
No 16	8.0	18.0	12.1000	2.6280	0.260%	9.12	-	-0.260%	-0.05	2.4020	393.8920	18.2360	18.2360	18.24
No 30	8.0	15.0	10.5000	2.6280	0.260%	7.91	-	-0.260%	-0.04	2.0840	341.8080	15.8240	15.8240	15.82
No 50	5.0	18.0	8.0000	2.6280	0.260%	6.03	-	-0.260%	-0.03	1.5880	260.4250	12.0570	12.0570	12.06
No 100	-	6.0	4.6000	2.6280	0.260%	3.47	-	-0.260%	-0.02	0.9130	149.7440	6.9330	6.9330	6.96
Pan	-	2.0	0.5000	2.5320	1.510%	0.36	-	-1.510%	-0.01	0.0990	15.6820	0.7260	0.7260	0.73
Total Grad%			100.0			72.64			-2.16	26.9970	3901.3240	180.6160	182.7780	182.8100

Fineness Mod			0.83
Q	22.0	72.0	37.9
I	16.0	44.0	26.4
W	21.0	64.0	35.7
CF Actual	48.7	73.3	58.9
WF Actual			35.7
AWF	23.0	49.0	34.70





Plastic Test Results

Batch Time	2:12 PM	% Air	3.25	Unit Wt w/o Air	148.22	Design w/c	0.450
Sample Time	2:21 PM	Bucket Weight	5.40	Unit Wt (pcf)	144.60	Actual w/c	0.450
Air Temp.	72.7	Bucket Full	41.55	Theorectial Air	2.44	Design Unit Wt	144.51
Mix Temp.	73.2	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.59
Slump, in.	3.5	Paste Volume (%)	23.71	Relative Yield	1.01	Bag Factor	5.60

Comments / Notes / Observations

KU Optimized Grading

Mix Percent by Weight	
No. 57	37.90
No. 8	26.40
Sand	35.70
Combined Gravity Dry	2.5320
Combined Absorption	1.5100

Workability Measurements		
Workability Index	5.7	inches
Pre Vib Slump	2.0	inches
Post Vib.Slump	5.0	inches
Spread Length	13.00	inches
Spread Width	12.75	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/02/10	1	2410	2480
	1	2550	
07/08/10	7	4800	4825
	7	4850	
07/15/10	14	4890	5170
	14	5450	
07/29/10	28	5540	5493
	28	5620	
	28	5320	
08/26/10	56	6130	6010
	56	5890	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/20/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 4.0
Mix Date Thursday, July 01, 2010 Mix Time: 2:12 PM

Measurements Required Before Making Specimens						
Specimen	Nominal Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8165	0.8130	11.62890	1.6295	9.9994
2	10.0000	0.8135	0.8140	11.57800	1.6275	9.9505
3	10.0000	0.8155	0.8140	11.61730	1.6295	9.9878

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
Specimen Age	Test date	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Friday, July 02, 2010	**0.1145**	**0.1109**	0.0036	**0.0638**	**0.1109**	-0.0471	**0.1032**	**0.1109**	-0.0077	-0.0171	**M/Rm**
		LENGTH CHANGE CALCULATIONS										
		Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Thursday, July 29, 2010	**0.1035**	**0.1004**	-0.0050	**0.0529**	**0.1004**	-0.0040	**0.0922**	**0.1004**	-0.0050	-0.0047	**Soak**
32	Monday, August 02, 2010	**0.1029**	**0.1001**	-0.0080	**0.0524**	**0.1001**	-0.0060	**0.0917**	**0.1001**	-0.0070	-0.0070	**Shrinkage Room**
35	Thursday, August 05, 2010	**0.1028**	**0.1003**	-0.0110	**0.0521**	**0.1003**	-0.0110	**0.0913**	**0.1003**	-0.0130	-0.0117	
42	Thursday, August 12, 2010	**0.1024**	**0.1002**	-0.0140	**0.0520**	**0.1002**	-0.0110	**0.0912**	**0.1002**	-0.0130	-0.0127	
56	Thursday, August 26, 2010	**0.1018**	**0.1001**	-0.0190	**0.0513**	**0.1001**	-0.0170	**0.0905**	**0.1001**	-0.0190	-0.0183	
84	Thursday, September 23, 2010	**0.1005**	**0.0998**	-0.0290	**0.0501**	**0.0998**	-0.0260	**0.0893**	**0.0998**	-0.0280	-0.0277	
140	Thursday, November 18, 2010	**0.1012**	**0.1013**	-0.0370	**0.0502**	**0.1013**	Erratic	**0.0894**	**0.1013**	Erratic	-0.0370	
252	Thursday, March 10, 2011	**0.1000**	**0.1004**	-0.0400	**0.0501**	**0.1004**	-0.0320	**0.0891**	**0.1004**	-0.0360	-0.0360	
476	Thursday, October 20, 2011	**0.1005**	**0.1010**	-0.0410	**0.0502**	**0.1010**	-0.0370	**0.0894**	**0.1010**	-0.0390	-0.0390	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/01/10

Material: Mix 4.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**76.41**	**77.17**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**120.260**	**121.780**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**121.020**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5320**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**23.3**	

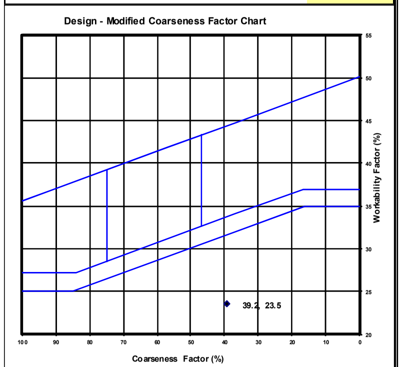
Reviewed By: Robert Varner, P.E. 7/10/2010

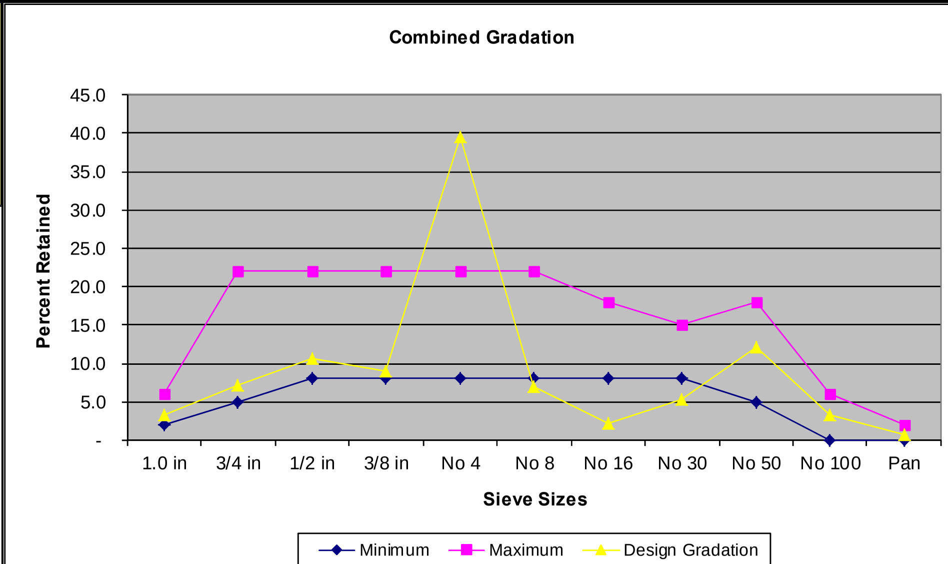
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT			Project:	090594							MIX	5.0
MIX NUMBER	GC081		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks								Set #:	GC081
MIX DESIGN INFO	Date:	7/12/2010		f'c:	4,000 psi		Design w/c ratio		0.450	Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)

Material	Min	Max	Design	DRY Specific Gravity	AGG Absorption	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.4500	13.45
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	3.2400	2.5170	1.720%	2.34	-	-1.720%	-0.08	0.6430	101.0170	4.6770	4.6770	4.72
3/4 in	5.0	22.0	7.1200	2.5170	1.720%	5.14	-	-1.720%	-0.18	1.4130	221.9880	10.2770	10.2770	10.28
1/2 in	8.0	22.0	10.6800	2.5170	1.720%	7.71	-	-1.720%	-0.27	2.1200	332.9830	15.4160	15.4160	15.42
3/8 in	8.0	22.0	8.9900	2.5170	1.720%	6.49	-	-1.720%	-0.22	1.7850	280.2910	12.9760	12.9760	12.98
No 4	8.0	22.0	39.5300	2.5170	1.720%	28.53	-	-1.720%	-0.98	7.8470	1232.4720	57.0590	57.0590	57.06
No 8	8.0	22.0	6.9500	2.5170	1.720%	5.02	-	-1.720%	-0.17	1.3800	216.6880	10.0320	10.0320	10.03
No 16	8.0	18.0	2.2000	2.5170	1.720%	1.59	-	-1.720%	-0.05	0.4370	68.5920	3.1760	3.1760	3.18
No 30	8.0	15.0	5.2500	2.5170	1.720%	3.79	-	-1.720%	-0.13	1.0420	163.6850	7.5780	7.5780	7.58
No 50	5.0	18.0	12.0800	2.5170	1.720%	8.72	-	-1.720%	-0.30	2.3980	376.6320	17.4370	17.4370	17.44
No 100	-	6.0	3.2500	2.5170	1.720%	2.35	-	-1.720%	-0.08	0.6450	101.3290	4.6910	4.6910	4.69
Pan	-	2.0	0.7200	2.5170	1.720%	0.52	-	-1.720%	-0.02	0.1430	22.4480	1.0390	1.0390	1.03
Total Grad%			100.0			72.18			-2.48	27.0020	3881.4050	179.6950	182.1780	182.2300

Fineness Mod			0.85
Q	23.0	72.0	30.0
I	16.0	44.0	46.5
W	21.0	59.0	23.5
CF Actual	#NUM!	#NUM!	39.2
WF Actual			23.5
AWF	24.9	47.1	22.50





Plastic Test Results

Batch Time	9:44 AM	% Air	1.75	Unit Wt w/o Air	147.43	Design w/c	0.450
Sample Time	9:53 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.80	Actual w/c	0.450
Air Temp.	72.5	Bucket Full	42.1	Theorectial Air	0.43	Design Unit Wt	143.75
Mix Temp.	73.2	Bucket Volume	0.250	Yield	1.24	Fine/Coarse	0.31
Slump, in.	3.00	Paste Volume (%)	24.15	Relative Yield	0.99	Bag Factor	5.60

Comments / Notes / Observations

Mix 5 - Target 40% No. 57, 35% No. 8, 25% Sand (Harsh)

Mix Percent by Weight	
No. 57	40.00
No. 8	35.00
Sand	25.00
Combined Gravity Dry	2.5170
Combined Absorption	1.7200

Workability Measurements		
Workability Index	4.5	inches
Pre Vib Slump	4.0	inches
Post Vib.Slump	5.75	inches
Spread Length	12.00	inches
Spread Width	12.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/13/10	1	2500	2525
	1	2550	
07/19/10	7	4620	4550
	7	4480	
07/26/10	14	5020	5075
	14	5130	
08/09/10	28	5610	5533
	28	5490	
	28	5500	
09/06/10	56	5920	5915
	56	5910	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/12/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 5.0
Mix Date Monday, July 12, 2010 Mix Time: 9:44 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8155	0.8140	11.64385	1.6295	10.0144
2	10.0000	0.8130	0.8135	11.61425	1.6265	9.9878
3	10.0000	0.8170	0.8150	11.61880	1.6320	9.9868

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Tuesday, July 13, 2010	**0.1184**	**0.0999**	0.0185	**0.0885**	**0.0999**	-0.0114	**0.0932**	**0.0999**	-0.0067	0.0001	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Monday, August 09, 2010	**0.1187**	**0.1001**	0.0010	**0.0888**	**0.1001**	0.0010	**0.0935**	**0.1001**	0.0010	0.0010	**Soak**
32	Friday, August 13, 2010	**0.1177**	**0.1002**	-0.0100	**0.0883**	**0.1002**	-0.0050	**0.0926**	**0.1002**	-0.0090	-0.0080	**Shrinkage Room**
35	Monday, August 16, 2010	**0.1174**	**0.1002**	-0.0130	**0.0876**	**0.1002**	-0.0120	**0.0924**	**0.1002**	-0.0110	-0.0120	
42	Monday, August 23, 2010	**0.1172**	**0.1001**	-0.0140	**0.0873**	**0.1001**	-0.0140	**0.0921**	**0.1001**	-0.0130	-0.0137	
56	Monday, September 06, 2010	**0.1165**	**0.1001**	-0.0210	**0.0866**	**0.1001**	-0.0210	**0.0915**	**0.1001**	-0.0190	-0.0203	
84	Monday, October 04, 2010	**0.1157**	**0.0998**	-0.0260	**0.0858**	**0.0998**	-0.0260	**0.0906**	**0.0998**	-0.0250	-0.0257	
140	Monday, November 29, 2010	**0.1163**	**0.1013**	-0.0350	**0.0864**	**0.1013**	-0.0350	**0.0917**	**0.1013**	-0.0290	-0.0330	
252	Monday, March 21, 2011	**0.1150**	**0.1003**	-0.0380	**0.0852**	**0.1003**	-0.0370	**0.0900**	**0.1003**	-0.0360	-0.0370	
476	Monday, October 31, 2011	**0.1156**	**0.1011**	-0.0400	**0.0855**	**0.1011**	-0.0420	**0.0906**	**0.1011**	-0.0380	-0.0400	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/12/10

Material: Mix 5.0 **Technician:** SB

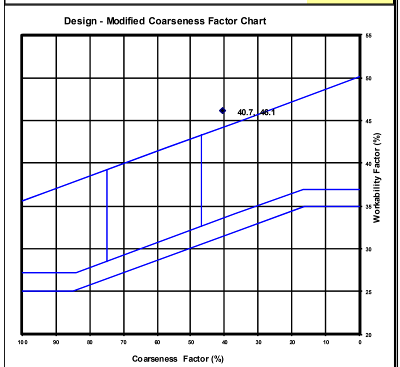
Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**75.79**	**75.33**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**119.020**	**118.100**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**118.560**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5170**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**24.4**	

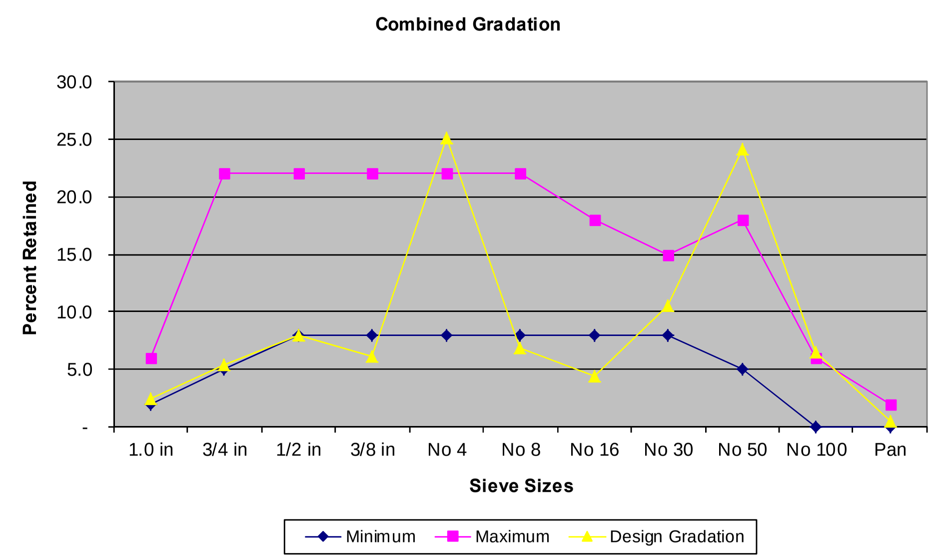
Reviewed By: Robert Varner, P.E. 7/12/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:		MDOT		Project:	090594									MIX	6.0
MIX NUMBER	GC104		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks										Set #:	GC104
MIX	Date:	7/13/2010		f'c:	4,000 psi		Design w/c ratio		0.450		Size(c.f.):	1.25		Factor:	0.05
DESIGN INFO	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch	
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	
Entrapped Air			2.50%							0.6750					
Water				1.000						4.1690	260.1450	12.0440	13.7870	13.79	
Cementitious 1				3.15						2.9410	578.1000	26.7640	26.7640	26.77	
1.0 in	2.0	6.0	2.4300	2.5530	1.230%	1.72	-	-1.230%	-0.04	0.4670	74.3840	3.4440	3.4440	3.44	
3/4 in	5.0	22.0	5.3400	2.5530	1.230%	3.78	-	-1.230%	-0.09	1.0260	163.4620	7.5680	7.5680	7.56	
1/2 in	8.0	22.0	8.0100	2.5530	1.230%	5.68	-	-1.230%	-0.14	1.5390	245.1930	11.3520	11.3520	11.35	
3/8 in	8.0	22.0	6.1800	2.5530	1.230%	4.38	-	-1.230%	-0.11	1.1870	189.1750	8.7580	8.7580	8.76	
No 4	8.0	22.0	25.1100	2.5530	1.230%	17.79	-	-1.230%	-0.44	4.8250	768.6390	35.5850	35.5850	35.58	
No 8	8.0	22.0	6.8500	2.5530	1.230%	4.85	-	-1.230%	-0.12	1.3160	209.6850	9.7080	9.7080	9.71	
No 16	8.0	18.0	4.4000	2.5530	1.230%	3.12	-	-1.230%	-0.08	0.8450	134.6880	6.2360	6.2360	6.24	
No 30	8.0	15.0	10.5000	2.5530	1.230%	7.44	-	-1.230%	-0.18	2.0180	321.4140	14.8800	14.8800	14.88	
No 50	5.0	18.0	24.1500	2.5530	1.230%	17.11	-	-1.230%	-0.42	4.6400	739.2530	34.2250	34.2250	34.23	
No 100	-	6.0	6.5000	2.5530	1.230%	4.61	-	-1.230%	-0.11	1.2490	198.9710	9.2120	9.2120	9.21	
Pan	-	2.0	0.5300	2.5530	1.230%	0.38	-	-1.230%	-0.01	0.1020	16.2240	0.7510	0.7510	0.75	
Total Grad%			100.0			70.86			-1.74	26.9990	3899.3330	180.5270	182.2700	182.2700	

Fineness Mod			0.89
Q	23.0	72.0	22.0
I	16.0	44.0	32.0
W	21.0	59.0	46.1
CF Actual	#NUM!	#NUM!	40.7
WF Actual			46.1
AWF	24.6	47.4	46.46





Comments / Notes / Observations

Mix 6 - Zone 4 As Sampled Blend
40.7/46.1

Mix Percent by Weight

No. 57	30.00
No. 8	20.00
Sand	50.00
Combined Gravity Dry	2.5530
Combined Absorption	1.2300

Workability Measurements

Workability Index	8.1	inches
Pre Vib Slump	2.75	inches
Post Vib.Slump	6.5	inches
Spread Length	15.25	inches
Spread Width	15.00	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/14/10	1	2490	2405
	1	2320	
07/20/10	7	4620	4445
	7	4270	
07/27/10	14	4680	4785
	14	4890	
08/10/10	28	5050	5170
	28	5420	
	28	5040	
09/07/10	56	5460	5460
	56	5460	

Technician who conducted tests:

Plastic Test Results

Batch Time	8:08 AM	% Air	5.75	Unit Wt w/o Air	148.13	Design w/c	0.450
Sample Time	8:17 AM	Bucket Weight	5.40	Unit Wt (pcf)	143.60	Actual w/c	0.450
Air Temp.	73.5	Bucket Full	41.3	Theorectial Air	3.06	Design Unit Wt	144.43
Mix Temp.	72.9	Bucket Volume	0.250	Yield	1.27	Fine/Coarse	0.85
Slump, in.	3	Paste Volume (%)	25.94	Relative Yield	1.02	Bag Factor	6.15

Reviewed by: Robert Varner, P.E. 8/9/2012

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 6.0
Mix Date Tuesday, July 13, 2010 Mix Time: 8:08 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8185	0.8155	11.65375	1.6340	10.0198
2	10.0000	0.8185	0.8150	11.62580	1.6335	9.9923
3	10.0000	0.8130	0.8150	11.64295	1.6280	10.0150

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Wednesday, July 14, 2010	**0.1300**	**0.0999**	0.0301	**0.1012**	**0.0999**	0.0013	**0.1183**	**0.0999**	0.0184	0.0166	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Tuesday, August 10, 2010	**0.1307**	**0.1001**	0.0050	**0.1018**	**0.1001**	0.0040	**0.1188**	**0.1001**	0.0030	0.0040	**Soak**
32	Saturday, August 14, 2010	**0.1295**	**0.1002**	-0.0080	**0.1007**	**0.1002**	-0.0080	**0.1177**	**0.1002**	-0.0090	-0.0083	**Shrinkage Room**
35	Tuesday, August 17, 2010	**0.1292**	**0.1000**	-0.0090	**0.1002**	**0.1000**	-0.0110	**0.1173**	**0.1000**	-0.0110	-0.0103	
42	Tuesday, August 24, 2010	**0.1291**	**0.1001**	-0.0110	**0.1001**	**0.1001**	-0.0130	**0.1173**	**0.1001**	-0.0120	-0.0120	
56	Tuesday, September 07, 2010	**0.1280**	**0.0999**	-0.0200	**0.0993**	**0.0999**	-0.0190	**0.1165**	**0.0999**	-0.0180	-0.0190	
84	Tuesday, October 05, 2010	**0.1272**	**0.0998**	-0.0270	**0.0984**	**0.0998**	-0.0270	**0.1157**	**0.0998**	-0.0250	-0.0263	
140	Tuesday, November 30, 2010	**0.1277**	**0.1013**	-0.0370	**0.0990**	**0.1013**	-0.0360	**0.1151**	**0.1013**	Erratic	-0.0365	
252	Tuesday, March 22, 2011	**0.1261**	**0.1001**	-0.0410	**0.0975**	**0.1001**	-0.0390	**0.1149**	**0.1001**	-0.0360	-0.0387	
476	Tuesday, November 01, 2011	**0.1266**	**0.1011**	-0.0460	**0.0980**	**0.1011**	-0.0440	**0.1150**	**0.1011**	-0.0450	-0.0450	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/13/10

Material: Mix 6.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.00**	**78.15**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.450**	**123.750**

Void Content	
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.600**
Bulk Dry Specific Gravity of Aggregate, S	**2.5530**
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**
Void Content, % = 100[(S*W)-M]/(S*W)	**22.3**

Reviewed By: Robert Varner, P.E. 7/14/2010

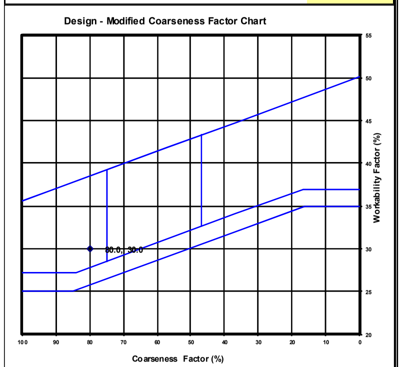
Burns Cooley Dennis, Inc - State Study No. 231

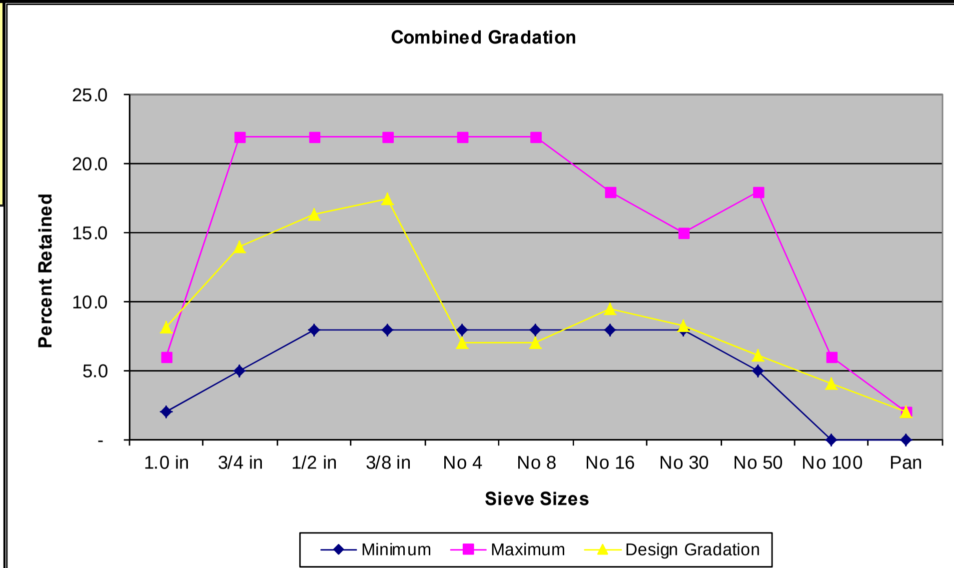
Customer:	MDOT	Project:	090594	MIX	7.0
MIX NUMBER	MM04	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	MM04

MIX DESIGN INFO	Date:	7/14/2010	f'c:	4,000 psi	Design w/c ratio	0.450	Size(c.f.):	1.25	Factor:	0.05

Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.4930	12.49
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	8.1700	2.4770	2.200%	5.95	-	-2.200%	-0.26	1.6640	257.2440	11.9090	11.9090	11.92
3/4 in	5.0	22.0	14.0000	2.4770	2.200%	10.20	-	-2.200%	-0.45	2.8520	440.8100	20.4080	20.4080	20.41
1/2 in	8.0	22.0	16.3300	2.4770	2.200%	11.90	-	-2.200%	-0.52	3.3270	514.1730	23.8040	23.8040	23.8
3/8 in	8.0	22.0	17.5000	2.4770	2.200%	12.75	-	-2.200%	-0.56	3.5650	551.0120	25.5100	25.5100	25.51
No 4	8.0	22.0	7.0000	2.4880	2.200%	5.12	-	-2.200%	-0.23	1.4260	221.3840	10.2490	10.2490	10.25
No 8	8.0	22.0	7.0000	2.4880	2.200%	5.12	-	-2.200%	-0.23	1.4260	221.3840	10.2490	10.2490	10.25
No 16	8.0	18.0	9.4500	2.6280	0.260%	7.31	-	-0.260%	-0.04	1.9250	315.6850	14.6150	14.6150	14.62
No 30	8.0	15.0	8.2200	2.6280	0.260%	6.36	-	-0.260%	-0.03	1.6740	274.5960	12.7130	12.7130	12.71
No 50	5.0	18.0	6.1600	2.6280	0.260%	4.76	-	-0.260%	-0.02	1.2550	205.7800	9.5270	9.5270	9.53
No 100	-	6.0	4.1100	2.6280	0.260%	3.18	-	-0.260%	-0.02	0.8370	137.2980	6.3560	6.3560	6.36
Pan	-	2.0	2.0500	2.5220	1.620%	1.52	-	-1.620%	-0.05	0.4180	65.7200	3.0430	3.0430	3.03
Total Grad%			100.0			74.19			-2.41	26.9980	3907.0310	180.8800	183.2880	183.2900

Fineness Mod			0.73
Q	23.0	72.0	56.0
I	16.0	44.0	14.0
W	21.0	59.0	30.0
CF Actual	#NUM!	#NUM!	80.0
WF Actual			30.0
AWF	24.4	47.6	27.87





Comments / Notes / Observations

Mix 7 - Manufactured Blend Target 80/30

Pan Blend Wts are 1.70, 0.43, 0.90 respectively.

Mix Percent by Weight	
No. 57	56.00
No. 8	14.00
Sand	30.00
Combined Gravity Dry	2.5220
Combined Absorption	1.6200

Workability Measurements		
Workability Index	3.8	inches
Pre Vib Slump	2.25	inches
Post Vib.Slump	4.5	inches
Spread Length	11.00	inches
Spread Width	11.00	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/15/10	1	2650	2600
	1	2550	
07/21/10	7	4010	4310
	7	4610	
07/28/10	14	4450	4630
	14	4810	
08/11/10	28	6030	5540
	28	5170	
	28	5420	
09/08/10	56	5730	5740
	56	5750	

Technician who conducted tests:

Plastic Test Results

Batch Time	1:59 PM	% Air	2.00	Unit Wt w/o Air	148.43	Design w/c	0.450
Sample Time	2:08 PM	Bucket Weight	5.40	Unit Wt (pcf)	147.80	Actual w/c	0.450
Air Temp.	77.0	Bucket Full	42.35	Theorectial Air	0.42	Design Unit Wt	144.72
Mix Temp.	73.5	Bucket Volume	0.250	Yield	1.24	Fine/Coarse	0.45
Slump, in.	2.5	Paste Volume (%)	22.22	Relative Yield	0.99	Bag Factor	5.15

Reviewed by: Robert Varner, P.E. 7/16/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 7.0
Mix Date Wednesday, July 14, 2010 Mix Time: 1:59 PM

Measurements Required Before Making Specimens						
Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8135	0.8160	11.61355	1.6295	9.9841
2	10.0000	0.8185	0.8150	11.64900	1.6335	10.0155
3	10.0000	0.8140	0.8140	11.63660	1.6280	10.0086

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
Specimen Age	Test date	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Thursday, July 15, 2010	**0.0901**	**0.0999**	-0.0098	**0.1253**	**0.0999**	0.0254	**0.1119**	**0.0999**	0.0120	0.0092	M/Rm
		LENGTH CHANGE CALCULATIONS										
		Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Wednesday, August 11, 2010	**0.0903**	**0.1002**	Erratic	**0.1264**	**0.1002**	0.0080	**0.1129**	**0.1002**	0.0070	0.0075	Soak
32	Sunday, August 15, 2010	**0.0893**	**0.1002**	Erratic	**0.1256**	**0.1002**	0.0000	**0.1121**	**0.1002**	-0.0010	-0.0005	Shrinkage Room
35	Wednesday, August 18, 2010	**0.0891**	**0.1001**	Erratic	**0.1252**	**0.1001**	-0.0030	**0.1117**	**0.1001**	-0.0040	-0.0035	
42	Wednesday, August 25, 2010	**0.0890**	**0.1001**	Erratic	**0.1251**	**0.1001**	-0.0040	**0.1116**	**0.1001**	-0.0050	-0.0045	
56	Wednesday, September 08, 2010	**0.0884**	**0.1000**	Erratic	**0.1245**	**0.1000**	-0.0090	**0.1109**	**0.1000**	-0.0110	-0.0100	
84	Wednesday, October 06, 2010	**0.0876**	**0.0998**	Erratic	**0.1237**	**0.0998**	-0.0150	**0.1100**	**0.0998**	-0.0180	-0.0165	
140	Wednesday, December 01, 2010	**0.0884**	**0.1013**	Erratic	**0.1243**	**0.1013**	-0.0240	**0.1080**	**0.1013**	Erratic	-0.0240	
252	Wednesday, March 23, 2011	**0.0870**	**0.1002**	Erratic	**0.1233**	**0.1002**	-0.0230	**0.1102**	**0.1002**	-0.0200	-0.0215	
476	Wednesday, November 02, 2011	**0.0875**	**0.1010**	Erratic	**0.1238**	**0.1010**	-0.0260	**0.1105**	**0.1010**	-0.0250	-0.0255	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/14/10

Material: Mix 7.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**77.89**	**77.83**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.230**	**123.110**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.170**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5220**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.6**	

Reviewed By: Robert Varner, P.E. 7/16/2010

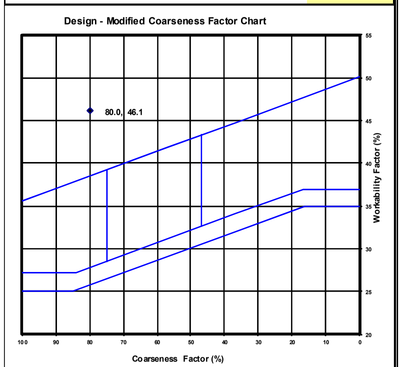
Burns Cooley Dennis, Inc - State Study No. 231

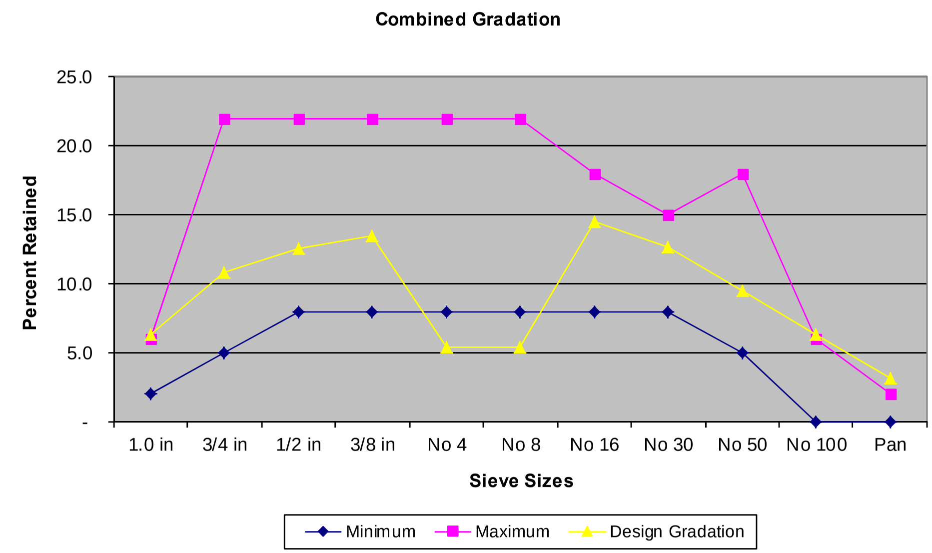
Customer: **MDOT** | Project: **090594** | MIX **8.0**

MIX NUMBER MM03 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM03

MIX DESIGN INFO	Date: 7/14/2010			f'c: 4,000 psi			Design w/c ratio 0.450			Size(c.f.): 1.25		Factor: 0.05	
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						4.1690	260.1450	12.0440	13.8980	13.9
Cementitious 1				3.15						2.9410	578.1000	26.7640	26.7640	26.76
1.0 in	2.0	6.0	6.2900	2.4770	2.200%	4.32	-	-2.200%	-0.19	1.2090	186.8110	8.6490	8.6490	8.66
3/4 in	5.0	22.0	10.7800	2.4770	2.200%	7.41	-	-2.200%	-0.33	2.0710	320.1620	14.8220	14.8220	14.81
1/2 in	8.0	22.0	12.5800	2.4770	2.200%	8.65	-	-2.200%	-0.38	2.4170	373.6210	17.2970	17.2970	17.3
3/8 in	8.0	22.0	13.4800	2.4770	2.200%	9.27	-	-2.200%	-0.41	2.5900	400.3510	18.5350	18.5350	18.54
No 4	8.0	22.0	5.3900	2.4880	2.200%	3.72	-	-2.200%	-0.16	1.0360	160.7920	7.4440	7.4440	7.44
No 8	8.0	22.0	5.3900	2.4880	2.200%	3.72	-	-2.200%	-0.16	1.0360	160.7920	7.4440	7.4440	7.44
No 16	8.0	18.0	14.5200	2.6280	0.260%	10.59	-	-0.260%	-0.06	2.7900	457.5270	21.1820	21.1820	21.18
No 30	8.0	15.0	12.6300	2.6280	0.260%	9.21	-	-0.260%	-0.05	2.4270	397.9730	18.4250	18.4250	18.43
No 50	5.0	18.0	9.4700	2.6280	0.260%	6.91	-	-0.260%	-0.04	1.8200	298.4010	13.8150	13.8150	13.82
No 100	-	6.0	6.3200	2.6280	0.260%	4.61	-	-0.260%	-0.02	1.2140	199.1440	9.2200	9.2200	9.22
Pan	-	2.0	3.1600	2.5450	1.310%	2.23	-	-1.310%	-0.06	0.6070	96.4270	4.4640	4.4640	4.46
Total Grad%			100.0			70.65			-1.85	27.0020	3890.2460	180.1050	181.9590	181.9600

Fineness Mod			0.78
Q	23.0	72.0	43.1
I	16.0	44.0	10.8
W	21.0	59.0	46.1
CF Actual	#NUM!	#NUM!	80.0
WF Actual			46.1
AWF	24.4	47.6	46.47





Plastic Test Results

Batch Time	10:28 AM	% Air	3.25	Unit Wt w/o Air	147.77	Design w/c	0.450
Sample Time	10:37 AM	Bucket Weight	5.40	Unit Wt (pcf)	145.40	Actual w/c	0.450
Air Temp.	74.2	Bucket Full	41.75	Theorectial Air	1.60	Design Unit Wt	144.07
Mix Temp.	70.4	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.90
Slump, in.	2.75	Paste Volume (%)	26.31	Relative Yield	1.00	Bag Factor	6.15

Comments / Notes / Observations

Mix 8 - Manufactured Blend Target 80/464.1

6.15 Sack Mix, Pan Blend Wts = 1.93, 0.48, 2.06

Mix Percent by Weight

No. 57	43.13
No. 8	10.78
Sand	46.10
Combined Gravity Dry	2.5450
Combined Absorption	1.3100

Workability Measurements

Workability Index	4.2	inches
Pre Vib Slump	2.25	inches
Post Vib.Slump	4.75	inches
Spread Length	12.25	inches
Spread Width	10.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/15/10	1	2770	2750
	1	2730	
07/21/10	7	4810	4855
	7	4900	
07/28/10	14	5220	5375
	14	5530	
08/11/10	28	5550	5897
	28	5930	
	28	6210	
09/08/10	56	6120	6115
	56	6110	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/16/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 8.0
Mix Date: Wednesday, July 14, 2010 Mix Time: 10:28 AM

Measurements Required Before Making Specimens						
Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8155	11.60920	1.6300	9.9792
2	10.0000	0.8145	0.8145	11.62270	1.6290	9.9937
3	10.0000	0.8145	0.8155	11.62865	1.6300	9.9987

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Thursday, July 15, 2010	**0.0844**	**0.0999**	-0.0155	**0.0982**	**0.0999**	-0.0017	**0.1049**	**0.0999**	0.0050	-0.0041	M/Rm

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Wednesday, August 11, 2010	**0.0849**	**0.1002**	0.0020	**0.0988**	**0.1002**	0.0030	**0.1054**	**0.1002**	0.0020	0.0023	Soak
32	Sunday, August 15, 2010	**0.0839**	**0.1002**	-0.0080	**0.0977**	**0.1002**	-0.0080	**0.1044**	**0.1002**	-0.0080	-0.0080	Shrinkage Room
35	Wednesday, August 18, 2010	**0.0836**	**0.1001**	-0.0100	**0.0974**	**0.1001**	-0.0100	**0.1041**	**0.1001**	-0.0100	-0.0100	
42	Wednesday, August 25, 2010	**0.0834**	**0.1001**	-0.0120	**0.0973**	**0.1001**	-0.0110	**0.1038**	**0.1001**	-0.0130	-0.0120	
56	Wednesday, September 08, 2010	**0.0828**	**0.1001**	-0.0180	**0.0967**	**0.1000**	-0.0160	**0.1030**	**0.1000**	-0.0200	-0.0180	
84	Wednesday, October 06, 2010	**0.0818**	**0.0997**	-0.0240	**0.0956**	**0.0997**	-0.0240	**0.1022**	**0.0997**	-0.0250	-0.0243	
140	Wednesday, December 01, 2010	**0.0828**	**0.1013**	-0.0300	**0.0966**	**0.1013**	-0.0300	**0.1030**	**0.1013**	-0.0330	-0.0310	
252	Wednesday, March 23, 2011	**0.0812**	**0.1002**	-0.0350	**0.0949**	**0.1002**	-0.0360	**0.1017**	**0.1002**	-0.0350	-0.0353	
476	Wednesday, November 02, 2011	**0.0815**	**0.1010**	-0.0400	**0.0958**	**0.1010**	-0.0350	**0.1023**	**0.1010**	-0.0370	-0.0373	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/14/10

Material: Mix 8.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**79.85**	**79.20**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**127.150**	**125.850**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**126.500**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5450**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.2**	

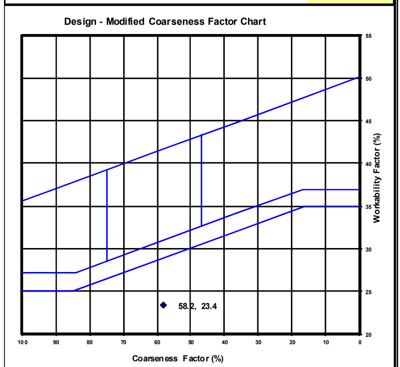
Reviewed By: Robert Varner, P.E. 7/16/2010

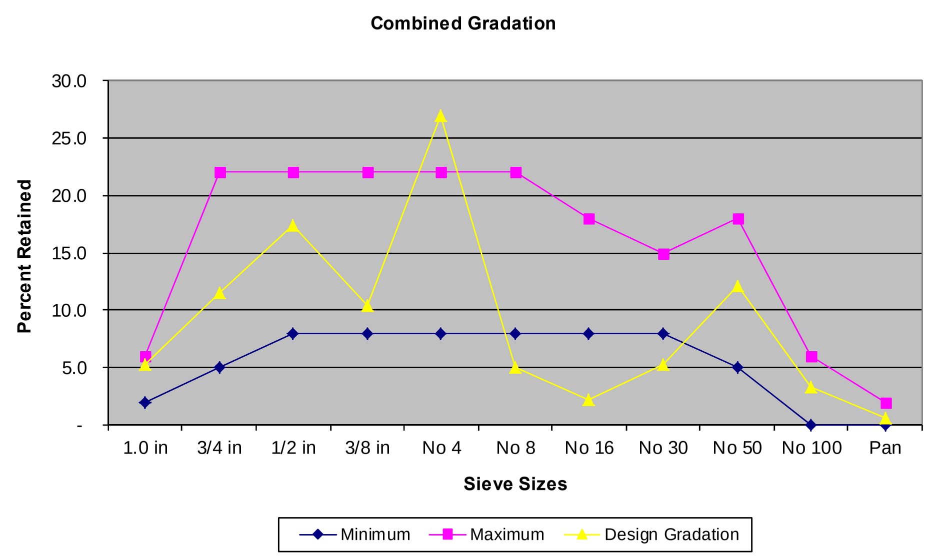
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594	MIX	9.0
MIX NUMBER	GC027	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	GC027

MIX DESIGN INFO	Date: 7/15/2010			f'c:	4,000 psi		Design w/c ratio	0.450		Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.4480	13.49
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	5.2700	2.5140	1.720%	3.80	-	-1.720%	-0.13	1.0460	164.1130	7.5980	7.5980	7.63
3/4 in	5.0	22.0	11.5700	2.5140	1.720%	8.34	-	-1.720%	-0.29	2.2970	360.3010	16.6810	16.6810	16.70
1/2 in	8.0	22.0	17.3600	2.5140	1.720%	12.51	-	-1.720%	-0.43	3.4460	540.6070	25.0280	25.0280	25.03
3/8 in	8.0	22.0	10.3900	2.5140	1.720%	7.49	-	-1.720%	-0.26	2.0630	323.5550	14.9790	14.9790	14.98
No 4	8.0	22.0	26.9600	2.5140	1.720%	19.43	-	-1.720%	-0.67	5.3520	839.5610	38.8690	38.8690	38.87
No 8	8.0	22.0	5.0800	2.5140	1.720%	3.66	-	-1.720%	-0.13	1.0080	158.1960	7.3240	7.3240	7.32
No 16	8.0	18.0	2.2000	2.5140	1.720%	1.59	-	-1.720%	-0.05	0.4370	68.5100	3.1720	3.1720	3.17
No 30	8.0	15.0	5.2500	2.5140	1.720%	3.78	-	-1.720%	-0.13	1.0420	163.4900	7.5690	7.5690	7.57
No 50	5.0	18.0	12.0800	2.5140	1.720%	8.71	-	-1.720%	-0.30	2.3980	376.1830	17.4160	17.4160	17.42
No 100	-	6.0	3.2500	2.5140	1.720%	2.34	-	-1.720%	-0.08	0.6450	101.2080	4.6860	4.6860	4.69
Pan	-	2.0	0.6200	2.5140	1.720%	0.45	-	-1.720%	-0.02	0.1230	19.3070	0.8940	0.8940	0.89
Total Grad%			100.0			72.11			-2.48	27.0060	3878.3110	179.5530	182.0340	182.1300

Fineness Mod			0.77
Q	23.0	72.0	44.6
I	16.0	44.0	32.0
W	21.0	59.0	23.4
CF Actual	#NUM!	#NUM!	58.2
WF Actual			23.4
AWF	23.0	49.0	22.39





Plastic Test Results

Batch Time	2:26 PM	% Air	1.50	Unit Wt w/o Air	147.29	Design w/c	0.450
Sample Time	2:36 PM	Bucket Weight	5.40	Unit Wt (pcf)	147.20	Actual w/c	0.452
Air Temp.	77.6	Bucket Full	42.2	Theorectial Air	0.06	Design Unit Wt	3.194
Mix Temp.	73.5	Bucket Volume	0.250	Yield	1.24	Fine/Coarse	0.305
Slump, in.	3.5	Paste Volume (%)	24.28	Relative Yield	0.99	Bag Factor	0.667

Comments / Notes / Observations

Mix 9 - As Sample Blend, 58.2/23.4

Mix Percent by Weight

No. 57	65.00
No. 8	10.00
Sand	25.00
Combined Gravity Dry	2.5140
Combined Absorption	1.7200

Workability Measurements

Workability Index	6.2	inches
Pre Vib Slump	3.0	inches
Post Vib.Slump	6.5	inches
Spread Length	13.00	inches
Spread Width	13.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/16/10	1	2570	2480
	1	2390	
07/22/10	7	4520	4650
	7	4780	
07/29/10	14	5090	5430
	14	5770	
08/12/10	28	6160	6027
	28	5970	
	28	5950	
09/09/10	56	6200	6275
	56	6350	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/16/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 9.0
Mix Date: Thursday, July 15, 2010   Mix Time: 2:26 PM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8145	11.62270	1.6290	9.9937
2	10.0000	0.8140	0.8155	11.63075	1.6295	10.0013
3	10.0000	0.8135	0.8130	11.61320	1.6265	9.9867

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Friday, July 16, 2010	**0.0981**	**0.1002**	-0.0021	**0.1062**	**0.1002**	0.0060	**0.0886**	**0.1002**	-0.0116	0.0000	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Thursday, August 12, 2010	**0.0983**	**0.1002**	0.0020	**0.1064**	**0.1002**	0.0020	**0.0888**	**0.1002**	0.0020	0.0020	**Soak**
32	Monday, August 16, 2010	**0.0975**	**0.1002**	-0.0060	**0.1053**	**0.1002**	-0.0090	**0.0878**	**0.1002**	-0.0080	-0.0077	**Shrinkage Room**
35	Thursday, August 19, 2010	**0.0974**	**0.1002**	-0.0070	**0.1053**	**0.1002**	-0.0090	**0.0877**	**0.1002**	-0.0090	-0.0083	
42	Thursday, August 26, 2010	**0.0971**	**0.1001**	-0.0090	**0.1050**	**0.1001**	-0.0110	**0.0875**	**0.1001**	-0.0100	-0.0100	
56	Thursday, September 09, 2010	**0.0962**	**0.0997**	-0.0140	**0.1042**	**0.0997**	-0.0150	**0.0866**	**0.0997**	-0.0150	-0.0147	
84	Thursday, October 07, 2010	**0.0956**	**0.0997**	-0.0200	**0.1035**	**0.0997**	-0.0220	**0.0858**	**0.0997**	-0.0230	-0.0217	
140	Thursday, December 02, 2010	**0.0964**	**0.1013**	-0.0280	**0.1044**	**0.1013**	-0.0290	**0.0867**	**0.1013**	-0.0300	-0.0290	
252	Thursday, March 24, 2011	**0.0951**	**0.1002**	-0.0300	**0.1031**	**0.1002**	-0.0310	**0.0853**	**0.1002**	-0.0330	-0.0313	
476	Thursday, November 03, 2011	**0.0958**	**0.1010**	-0.0310	**0.1037**	**0.1010**	-0.0330	**0.0858**	**0.1010**	-0.0360	-0.0333	

Note: Lowest Reading Value Recorded.   Reviewed By Robert Varner, P.E.   Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/15/10

Material: Mix 9.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**74.60**	**76.50**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**116.630**	**120.440**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**118.540**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5140**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**24.3**	

Reviewed By: Robert Varner, P.E. 7/16/2010

Burns Cooley Dennis, Inc - State Study No. 231

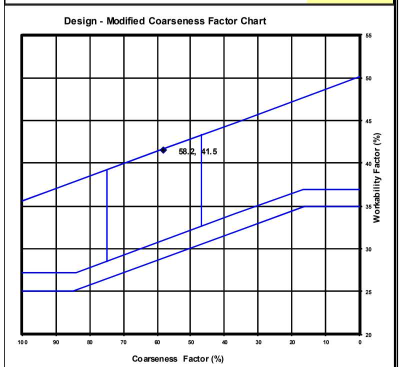
Customer: **MDOT** | Project: **090594** | MIX **10.0**

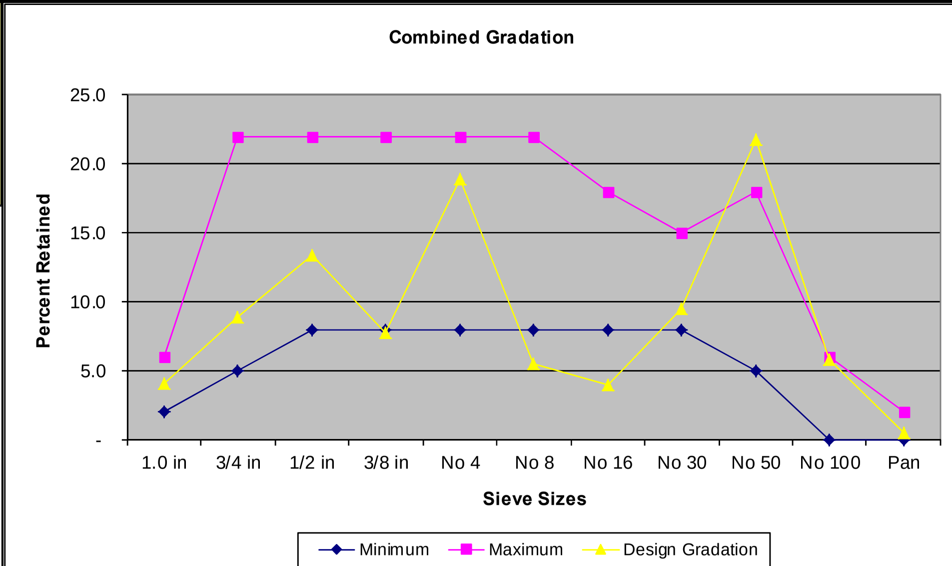
MIX NUMBER GC053 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: GC053

MIX DESIGN INFO | Date: 7/15/2010 | f'c: 4,000 psi | Design w/c ratio 0.450 | Size(c.f.): 1.25 | Factor: 0.05

Material	Min (% Retained MDOT)	Max (% Retained MDOT)	Design	DRY Specific Gravity	AGG Absorption	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						4.0670	253.8000	11.7500	13.6450	13.65
Cementitious 1				3.15						2.8690	564.0000	26.1110	26.1110	26.11
1.0 in	2.0	6.0	4.0500	2.5430	1.330%	2.88	-	-1.330%	-0.08	0.7850	124.6070	5.7690	5.7690	5.78
3/4 in	5.0	22.0	8.9000	2.5430	1.330%	6.34	-	-1.330%	-0.17	1.7260	273.8270	12.6770	12.6770	12.67
1/2 in	8.0	22.0	13.3500	2.5430	1.330%	9.51	-	-1.330%	-0.25	2.5880	410.7410	19.0160	19.0160	19.02
3/8 in	8.0	22.0	7.7500	2.5430	1.330%	5.52	-	-1.330%	-0.15	1.5030	238.4450	11.0390	11.0390	11.04
No 4	8.0	22.0	18.9400	2.5430	1.330%	13.49	-	-1.330%	-0.36	3.6720	582.7290	26.9780	26.9780	26.97
No 8	8.0	22.0	5.5200	2.5430	1.330%	3.93	-	-1.330%	-0.10	1.0700	169.8340	7.8630	7.8630	7.87
No 16	8.0	18.0	3.9600	2.5430	1.330%	2.82	-	-1.330%	-0.08	0.7680	121.8380	5.6410	5.6410	5.64
No 30	8.0	15.0	9.4500	2.5430	1.330%	6.73	-	-1.330%	-0.18	1.8320	290.7490	13.4610	13.4610	13.46
No 50	5.0	18.0	21.7400	2.5430	1.330%	15.48	-	-1.330%	-0.41	4.2150	668.8760	30.9660	30.9660	30.97
No 100	-	6.0	5.8500	2.5430	1.330%	4.17	-	-1.330%	-0.11	1.1340	179.9870	8.3330	8.3330	8.33
Pan	-	2.0	0.5000	2.5430	1.330%	0.36	-	-1.330%	-0.01	0.0970	15.3840	0.7120	0.7120	0.71
Total Grad%			100.0			71.23			-1.89	27.0010	3894.8170	180.3160	182.2110	182.2200

Fineness Mod			0.82
Q	23.0	72.0	34.1
I	16.0	44.0	24.5
W	21.0	59.0	41.5
CF Actual	#NUM!	#NUM!	58.2
WF Actual			41.5
AWF	23.0	49.0	41.50





Comments / Notes / Observations

Mix 10 Zone 2/4 Blend; 58.2/41.5

Mix Percent by Weight	
No. 57	50.00
No. 8	5.00
Sand	45.00
Combined Gravity Dry	2.5430
Combined Absorption	1.3300

Workability Measurements		
Workability Index	9.7	inches
Pre Vib Slump	3.25	inches
Post Vib.Slump	8.75	inches
Spread Length	17.00	inches
Spread Width	15.00	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/16/10	1	2400	2315
	1	2230	
07/22/10	7	4240	4350
	7	4460	
07/29/10	14	4840	4860
	14	4880	
08/12/10	28	5810	5613
	28	5400	
	28	5630	
09/09/10	56	5510	5580
	56	5650	

Technician who conducted tests:

Plastic Test Results

Batch Time	3:29 PM	% Air	3.75	Unit Wt w/o Air	147.95	Design w/c	0.450
Sample Time	3:38 PM	Bucket Weight	5.40	Unit Wt (pcf)	144.40	Actual w/c	0.450
Air Temp.	77.8	Bucket Full	41.5	Theorectial Air	2.40	Design Unit Wt	144.25
Mix Temp.	75.4	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.71
Slump, in.	3.25	Paste Volume (%)	25.46	Relative Yield	1.01	Bag Factor	6.00

Reviewed by: Robert Varner, P.E. 7/16/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157
BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 10.0
Mix Date: Thursday, July 15, 2010 Mix Time: 3:29 PM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8140	11.64210	1.6285	10.0136
2	10.0000	0.8120	0.8135	11.63555	1.6255	10.0101
3	10.0000	0.8130	0.8140	11.61135	1.6270	9.9844

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Friday, July 16, 2010	**0.1184**	**0.1002**	0.0182	**0.1111**	**0.1002**	0.0109	**0.0865**	**0.1002**	-0.0137	0.0051	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Thursday, August 12, 2010	**0.1186**	**0.1002**	0.0020	**0.1120**	**0.1002**	0.0090	**0.0880**	**0.1002**	Erratic	0.0055	**Soak**
32	Monday, August 16, 2010	**0.1178**	**0.1002**	-0.0060	**0.1108**	**0.1002**	-0.0030	**0.0870**	**0.1002**	Erratic	-0.0045	**Shrinkage Room**
35	Thursday, August 19, 2010	**0.1174**	**0.1002**	-0.0100	**0.1107**	**0.1002**	-0.0040	**0.0868**	**0.1002**	Erratic	-0.0070	
42	Thursday, August 26, 2010	**0.1172**	**0.1001**	-0.0110	**0.1103**	**0.1001**	-0.0070	**0.0865**	**0.1001**	Erratic	-0.0090	
56	Thursday, September 09, 2010	**0.1163**	**0.0997**	-0.0160	**0.1093**	**0.0997**	-0.0130	**0.0856**	**0.0997**	Erratic	-0.0145	
84	Thursday, October 07, 2010	**0.1154**	**0.0997**	-0.0250	**0.1084**	**0.0997**	-0.0220	**0.0847**	**0.0997**	Erratic	-0.0235	
140	Thursday, December 02, 2010	**0.1164**	**0.1013**	-0.0310	**0.1093**	**0.1013**	-0.0290	**0.0858**	**0.1013**	Erratic	-0.0300	
252	Thursday, March 24, 2011	**0.1150**	**0.1002**	-0.0340	**0.1078**	**0.1002**	-0.0330	**0.0844**	**0.1002**	Erratic	-0.0335	
476	Thursday, November 03, 2011	**0.1154**	**0.1010**	-0.0380	**0.1084**	**0.1010**	-0.0350	**0.0850**	**0.1010**	Erratic	-0.0365	

Note: Lowest Reading Value Recorded. Reviewed By Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/15/10

Material: Mix 10.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.25**	**77.35**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.950**	**122.140**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.050**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5430**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**22.3**	

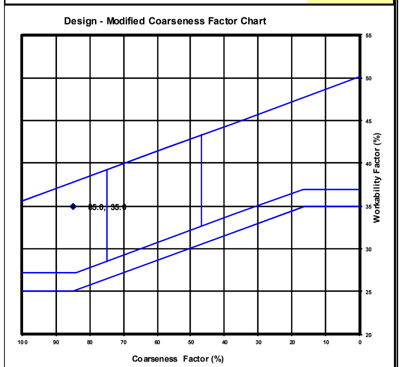
Reviewed By: Robert Varner, P.E. 7/16/2010

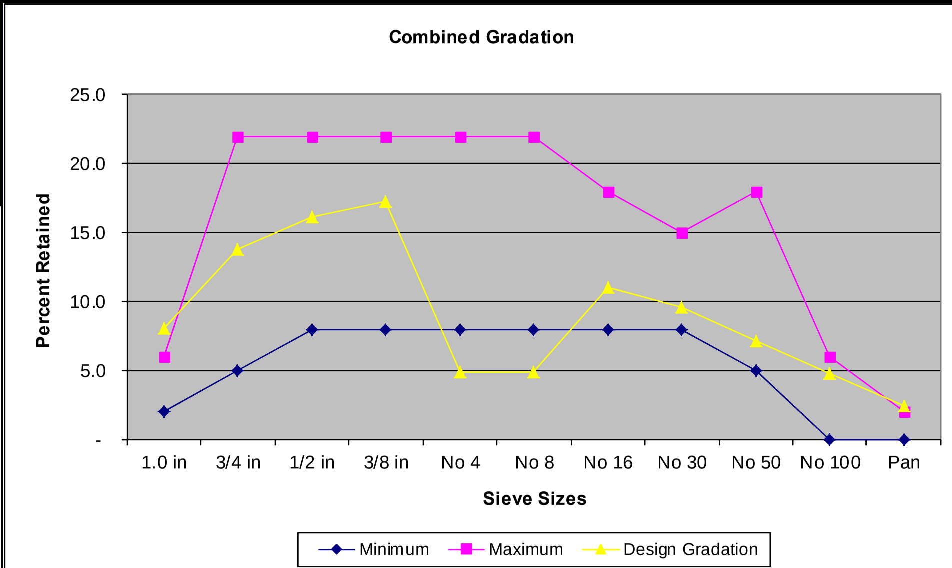
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594	MIX	11.0
MIX NUMBER	MM05	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	MM05
Date:	7/22/2010	f'c: 4,000 psi	Design w/c ratio 0.450	Size(c.f.): 1.25	Factor: 0.05

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.3790	12.38
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	8.0600	2.4770	2.200%	5.87	-	-2.200%	-0.26	1.6420	253.7800	11.7490	11.7490	11.75
3/4 in	5.0	22.0	13.8100	2.4770	2.200%	10.07	-	-2.200%	-0.44	2.8130	434.8270	20.1310	20.1310	20.14
1/2 in	8.0	22.0	16.1100	2.4770	2.200%	11.74	-	-2.200%	-0.52	3.2820	507.2460	23.4840	23.4840	23.49
3/8 in	8.0	22.0	17.2700	2.4770	2.200%	12.59	-	-2.200%	-0.55	3.5180	543.7700	25.1750	25.1750	25.17
No 4	8.0	22.0	4.8800	2.4880	2.200%	3.57	-	-2.200%	-0.16	0.9940	154.3360	7.1450	7.1450	7.15
No 8	8.0	22.0	4.8800	2.4880	2.200%	3.57	-	-2.200%	-0.16	0.9940	154.3360	7.1450	7.1450	7.15
No 16	8.0	18.0	11.0300	2.6280	0.260%	8.53	-	-0.260%	-0.04	2.2470	368.4660	17.0590	17.0590	17.06
No 30	8.0	15.0	9.5900	2.6280	0.260%	7.42	-	-0.260%	-0.04	1.9540	320.3620	14.8320	14.8320	14.83
No 50	5.0	18.0	7.1900	2.6280	0.260%	5.56	-	-0.260%	-0.03	1.4650	240.1880	11.1200	11.1200	11.12
No 100	-	6.0	4.7900	2.6280	0.260%	3.70	-	-0.260%	-0.02	0.9760	160.0140	7.4080	7.4080	7.41
Pan	-	2.0	2.4000	2.4770	2.200%	1.75	-	-2.200%	-0.08	0.4890	75.5670	3.4980	3.4980	3.5
Total Grad%			100.0			74.37			-2.29	27.0030	3914.8370	181.2430	183.5370	183.5600

Fineness Mod			0.73
Q	23.0	72.0	55.3
I	16.0	44.0	9.8
W	21.0	59.0	35.0
CF Actual	52.9	69.1	85.0
WF Actual			35.0
AWF	25.3	46.7	32.87





Plastic Test Results

Batch Time	8:55 AM	% Air	2.50	Unit Wt w/o Air	148.69	Design w/c	0.450
Sample Time	9:04 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.60	Actual w/c	0.450
Air Temp.	74.0	Bucket Full	42.05	Theorectial Air	1.41	Design Unit Wt	144.98
Mix Temp.	71	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.57
Slump, in.	2.75	Paste Volume (%)	22.01	Relative Yield	1.00	Bag Factor	5.15

Comments / Notes / Observations

Mix 11.0 - Manufactured Blend; 85/35

Mix Percent by Weight	
No. 57	55.20
No. 8	9.75
Sand	35.00
Combined Gravity Dry	2.5290
Combined Absorption	1.5200

Workability Measurements		
Workability Index	5.5	inches
Pre Vib Slump	2.25	inches
Post Vib.Slump	5.5	inches
Spread Length	12.50	inches
Spread Width	12.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/23/10	1	2660	2675
	1	2690	
07/29/10	7	4640	4825
	7	5010	
08/05/10	14	5270	5290
	14	5310	
08/19/10	28	5400	5360
	28	5170	
	28	5510	
09/16/10	56	6020	5985
	56	5950	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/22/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 11.0
Mix Date Thursday, July 22, 2010 Mix Time: 8:55 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8150	0.8140	11.62945	1.6290	10.0005
2	10.0000	0.8150	0.8130	11.59930	1.6280	9.9713
3	10.0000	0.8140	0.8150	11.63155	1.6290	10.0026

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Friday, July 23, 2010	**0.1057**	**0.1003**	0.0054	**0.0748**	**0.1003**	-0.0255	**0.1068**	**0.1004**	0.0064	-0.0046	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Thursday, August 19, 2010	**0.1060**	**0.1002**	0.0040	**0.0750**	**0.1002**	0.0030	**0.1068**	**0.1002**	0.0020	0.0030	**Soak**
32	Monday, August 23, 2010	**0.1053**	**0.1001**	-0.0020	**0.0746**	**0.1001**	0.0000	**0.1063**	**0.1001**	-0.0020	-0.0013	**Shrinkage Room**
35	Thursday, August 26, 2010	**0.1050**	**0.1001**	-0.0050	**0.0743**	**0.1001**	-0.0030	**0.1061**	**0.1001**	-0.0040	-0.0040	
42	Thursday, September 02, 2010	**0.1046**	**0.1002**	-0.0100	**0.0741**	**0.1002**	-0.0060	**0.1058**	**0.1002**	-0.0080	-0.0080	
56	Thursday, September 16, 2010	**0.1038**	**0.0997**	-0.0130	**0.0732**	**0.0997**	-0.0100	**0.1049**	**0.0997**	-0.0120	-0.0117	
84	Thursday, October 14, 2010	**0.1032**	**0.0998**	-0.0200	**0.0725**	**0.0998**	-0.0180	**0.1039**	**0.0998**	-0.0230	-0.0203	
140	Thursday, December 09, 2010	**0.1041**	**0.1013**	-0.0260	**0.0734**	**0.1013**	-0.0240	**0.1049**	**0.1013**	-0.0280	-0.0260	
252	Thursday, March 31, 2011	**0.1030**	**0.1004**	-0.0280	**0.0725**	**0.1004**	-0.0240	**0.1036**	**0.1004**	-0.0320	-0.0280	
476	Thursday, November 10, 2011	**0.1034**	**0.1010**	-0.0300	**0.0728**	**0.1010**	-0.0270	**0.1039**	**0.1010**	-0.0350	-0.0307	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/22/10

Material: Mix 11.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.91**	**78.63**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**125.270**	**124.710**

Void Content	
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.990**
Bulk Dry Specific Gravity of Aggregate, S	**2.5290**
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**
Void Content, % = 100[(S*W)-M]/(S*W)	**20.7**

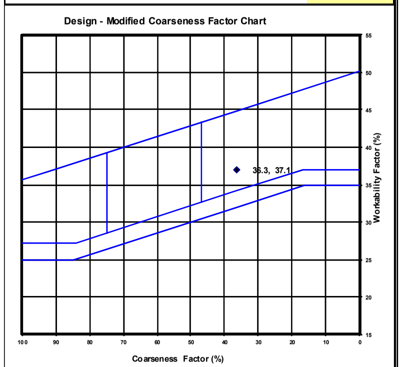
Reviewed By: Robert Varner, P.E. 7/22/2010

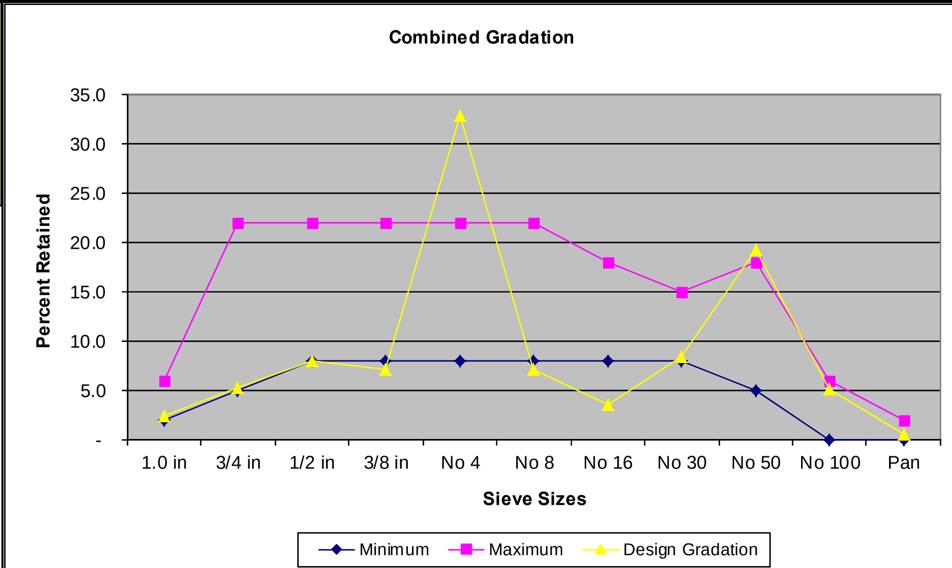
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594	MIX	12.0
MIX NUMBER	GC106	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	GC106
Date:	7/19/2010	f'c: 4,000 psi	Design w/c ratio 0.450	Size(c.f.): 1.25	Factor: 0.05

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0350	13.04
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	2.4300	2.5390	1.420%	1.77	-	-1.420%	-0.05	0.4820	76.4250	3.5380	3.5380	3.53
3/4 in	5.0	22.0	5.3400	2.5390	1.420%	3.89	-	-1.420%	-0.11	1.0600	167.9460	7.7750	7.7750	7.79
1/2 in	8.0	22.0	8.0100	2.5390	1.420%	5.83	-	-1.420%	-0.17	1.5900	251.9200	11.6630	11.6630	11.66
3/8 in	8.0	22.0	7.0800	2.5390	1.420%	5.15	-	-1.420%	-0.15	1.4050	222.6710	10.3090	10.3090	10.31
No 4	8.0	22.0	32.8900	2.5390	1.420%	23.94	-	-1.420%	-0.68	6.5290	1034.4120	47.8890	47.8890	47.89
No 8	8.0	22.0	7.1900	2.5390	1.420%	5.23	-	-1.420%	-0.15	1.4270	226.1300	10.4690	10.4690	10.47
No 16	8.0	18.0	3.5200	2.5390	1.420%	2.56	-	-1.420%	-0.07	0.6990	110.7060	5.1250	5.1250	5.13
No 30	8.0	15.0	8.4000	2.5390	1.420%	6.12	-	-1.420%	-0.17	1.6670	264.1850	12.2310	12.2310	12.23
No 50	5.0	18.0	19.3200	2.5390	1.420%	14.07	-	-1.420%	-0.40	3.8350	607.6270	28.1310	28.1310	28.13
No 100	-	6.0	5.2000	2.5390	1.420%	3.79	-	-1.420%	-0.11	1.0320	163.5430	7.5710	7.5710	7.57
Pan	-	2.0	0.6200	2.5390	1.420%	0.45	-	-1.420%	-0.01	0.1230	19.4990	0.9030	0.9030	0.91
Total Grad%			100.0			72.80			-2.07	26.9980	3908.3440	180.9410	183.0090	183.0300

Fineness Mod			0.89
Q	23.0	72.0	22.9
I	16.0	44.0	40.1
W	21.0	59.0	37.1
CF Actual	48.0	74.0	36.3
WF Actual			37.1
AWF	25.4	46.6	36.06





Plastic Test Results

Batch Time	9:55 AM	% Air	3.00	Unit Wt w/o Air	148.48	Design w/c	0.450
Sample Time	10:04 AM	Bucket Weight	5.40	Unit Wt (pcf)	145.80	Actual w/c	0.450
Air Temp.	73.6	Bucket Full	41.85	Theorectial Air	1.80	Design Unit Wt	144.76
Mix Temp.	71	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.59
Slump, in.	2.5	Paste Volume (%)	23.88	Relative Yield	1.00	Bag Factor	5.60

Comments / Notes / Observations

Mix 12 - As Graded Blend; 36.3 / 37.1

Mix Percent by Weight	
No. 57	30.00
No. 8	30.00
Sand	40.00
Combined Gravity Dry	2.5390
Combined Absorption	1.4200

Workability Measurements		
Workability Index	6.4	inches
Pre Vib Slump	1.75	inches
Post Vib.Slump	5.5	inches
Spread Length	13.25	inches
Spread Width	13.00	inches

Strength Test Results

Date	AGE (4x8 CYLINDERS)	psi	Avg. psi
07/20/10	1	2300	2270
	1	2240	
07/26/10	7	4170	4170
	7	4170	
08/02/10	14	5040	4845
	14	4650	
08/16/10	28	5300	5247
	28	5250	
	28	5190	
09/13/10	56	5530	5530
	56	5530	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/20/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 12.0
Mix Date: Monday, July 19, 2010   Mix Time: 9:55 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8140	0.8165	11.61880	1.6305	9.9883
2	10.0000	0.8140	0.8130	11.64045	1.6270	10.0135
3	10.0000	0.8145	0.8130	11.61450	1.6275	9.9870

SHRINKAGE TESTING - ASTM C157

INITIAL READINGS

	Gage Length (in.)	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
	10											
Specimen Age	**Test date**	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Tuesday, July 20, 2010	**0.0961**	**0.1004**	-0.0043	**0.1185**	**0.1004**	0.0181	**0.0925**	**0.1004**	-0.0079	0.0020	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Monday, August 16, 2010	**0.0957**	**0.1002**	-0.0020	**0.1183**	**0.1002**	0.0000	**0.0935**	**0.1002**	Erratic	-0.0010	**Soak**
32	Friday, August 20, 2010	**0.0950**	**0.1001**	-0.0080	**0.1175**	**0.1001**	-0.0070	**0.0927**	**0.1001**	Erratic	-0.0075	**Shrinkage Room**
35	Monday, August 23, 2010	**0.0949**	**0.1001**	-0.0090	**0.1175**	**0.1001**	-0.0070	**0.0924**	**0.1001**	Erratic	-0.0080	
42	Monday, August 30, 2010	**0.0944**	**0.1001**	-0.0140	**0.1168**	**0.1001**	-0.0140	**0.0917**	**0.1001**	Erratic	-0.0140	
56	Monday, September 13, 2010	**0.0936**	**0.0998**	-0.0190	**0.1161**	**0.0998**	-0.0180	**0.0910**	**0.0998**	Erratic	-0.0185	
84	Monday, October 11, 2010	**0.0928**	**0.0997**	-0.0260	**0.1154**	**0.0997**	-0.0240	**0.0902**	**0.0997**	Erratic	-0.0250	
140	Monday, December 06, 2010	**0.0924**	**0.1004**	-0.0370	**0.1150**	**0.1004**	-0.0350	**0.0905**	**0.1004**	Erratic	-0.0360	
252	Monday, March 28, 2011	**0.0924**	**0.1004**	-0.0370	**0.1149**	**0.1004**	-0.0360	**0.0896**	**0.1004**	Erratic	-0.0365	
476	Monday, November 07, 2011	**0.0926**	**0.1010**	-0.0410	**0.1152**	**0.1010**	-0.0390	**0.0905**	**0.1010**	Erratic	-0.0400	

Note: Lowest Reading Value Recorded.   Reviewed By: Robert Varner, P.E.   Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/19/10

Material: Mix 12.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**77.37**	**77.42**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**122.180**	**122.280**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**122.230**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5390**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**22.7**	

Reviewed By: Robert Varner, P.E. 7/20/2010

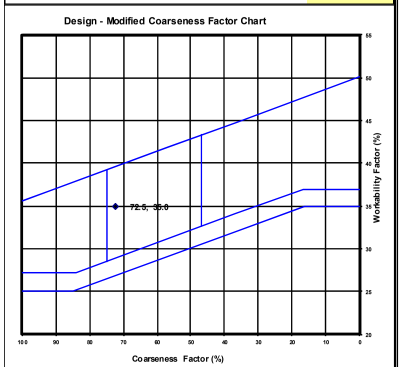
Burns Cooley Dennis, Inc - State Study No. 231

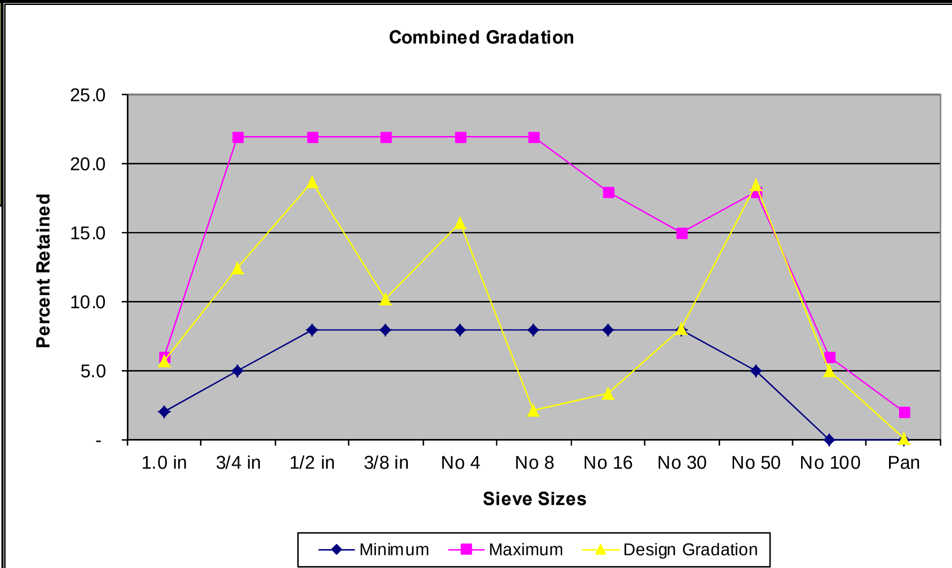
Customer: **MDOT** | Project: **090594** | MIX **13.0**

MIX NUMBER MM08 | **Notes:** Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM08

MIX DESIGN INFO	Date:	7/26/2010		f'c:	4,000 psi		Design w/c ratio		0.450		Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.3140	12.31
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	5.6800	2.4770	2.200%	4.14	-	-2.200%	-0.18	1.1570	178.8430	8.2800	8.2800	8.30
3/4 in	5.0	22.0	12.4800	2.4770	2.200%	9.10	-	-2.200%	-0.40	2.5420	392.9500	18.1920	18.1920	18.19
1/2 in	8.0	22.0	18.7200	2.4770	2.200%	13.64	-	-2.200%	-0.60	3.8130	589.4250	27.2880	27.2880	27.29
3/8 in	8.0	22.0	10.2400	2.4770	2.200%	7.46	-	-2.200%	-0.33	2.0860	322.4210	14.9270	14.9270	14.93
No 4	8.0	22.0	15.7300	2.4880	2.200%	11.52	-	-2.200%	-0.51	3.2040	497.4800	23.0310	23.0310	23.03
No 8	8.0	22.0	2.1500	2.4880	2.200%	1.57	-	-2.200%	-0.07	0.4380	67.9960	3.1480	3.1480	3.15
No 16	8.0	18.0	3.3700	2.6280	0.260%	2.61	-	-0.260%	-0.01	0.6870	112.5780	5.2120	5.2120	5.21
No 30	8.0	15.0	8.0500	2.6280	0.260%	6.22	-	-0.260%	-0.03	1.6400	268.9170	12.4500	12.4500	12.45
No 50	5.0	18.0	18.5200	2.6280	0.260%	14.32	-	-0.260%	-0.07	3.7730	618.6760	28.6420	28.6420	28.64
No 100	-	6.0	4.9800	2.6280	0.260%	3.85	-	-0.260%	-0.02	1.0140	166.3610	7.7020	7.7020	7.7
Pan	-	2.0	0.0800	2.5300	1.520%	0.06	-	-1.520%	0.00	0.0160	2.5730	0.1190	0.1190	0.12
Total Grad%			100.0			74.50			-2.23	26.9990	3920.1650	181.4880	183.7170	183.7300

Fineness Mod			0.76
Q	23.0	72.0	47.1
I	16.0	44.0	17.9
W	21.0	59.0	35.0
CF Actual	52.9	69.1	72.5
WF Actual			35.0
AWF	23.5	48.5	32.88





Plastic Test Results

Batch Time	8:58 AM	% Air	3.25	Unit Wt w/o Air	148.92	Design w/c	0.450
Sample Time	9:07 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.80	Actual w/c	0.450
Air Temp.	73.6	Bucket Full	42.10	Theorectial Air	1.42	Design Unit Wt	145.20
Mix Temp.	73.1	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.57
Slump, in.	2.50	Paste Volume (%)	22.02	Relative Yield	1.00	Bag Factor	5.15

Comments / Notes / Observations

Mix 13 - Target 72.5/35

Pan Blend = .06, .02, .04 respectively

Mix Percent by Weight	
No. 57	47.10
No. 8	17.90
Sand	35.00
Combined Gravity Dry	2.5300
Combined Absorption	1.5200

Workability Measurements		
Workability Index	5.9	inches
Pre Vib Slump	2.0	inches
Post Vib.Slump	5.5	inches
Spread Length	12.50	inches
Spread Width	13.00	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/27/10	1	2190	2135
	1	2080	
08/02/10	7	4280	4195
	7	4110	
08/09/10	14	4120	4475
	14	4830	
08/23/10	28	4910	4883
	28	4870	
	28	4870	
09/20/10	56	5290	5305
	56	5320	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/26/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 13.0
Mix Date: Monday, July 26, 2010
Mix Time: 8:58 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8140	11.62435	1.6285	9.9959
2	10.0000	0.8145	0.8150	11.67025	1.6295	10.0408
3	10.0000	0.8135	0.8150	11.63530	1.6285	10.0068

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (Inches)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (Inches)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (Inches)	Average (Inches)	
1	Tuesday, July 27, 2010	**0.1020**	**0.1003**	0.0017	**0.1461**	**0.1003**	0.0458	**0.1124**	**0.1003**	0.0121	0.0199	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Monday, August 23, 2010	**0.1012**	**0.1001**	-0.0060	**0.1461**	**0.1001**	0.0020	**0.1124**	**0.1001**	0.0020	-0.0007	**Soak**
32	Friday, August 27, 2010	**0.1007**	**0.1001**	-0.0110	**0.1456**	**0.1001**	-0.0030	**0.1120**	**0.1001**	-0.0020	-0.0053	**Shrinkage Room**
35	Monday, August 30, 2010	**0.1004**	**0.1001**	-0.0140	**0.1453**	**0.1001**	-0.0060	**0.1116**	**0.1001**	-0.0060	-0.0087	
42	Monday, September 06, 2010	**0.1001**	**0.1001**	-0.0170	**0.1448**	**0.1001**	-0.0110	**0.1110**	**0.1001**	-0.0120	-0.0133	
56	Monday, September 20, 2010	**0.0991**	**0.0996**	-0.0220	**0.1441**	**0.0996**	-0.0130	**0.1101**	**0.0996**	-0.0160	-0.0170	
84	Monday, October 18, 2010	**0.0988**	**0.1000**	-0.0290	**0.1437**	**0.1000**	-0.0210	**0.1098**	**0.1000**	-0.0230	-0.0243	
140	Monday, December 13, 2010	**0.0994**	**0.1012**	-0.0350	**0.1444**	**0.1012**	-0.0260	**0.1103**	**0.1012**	-0.0300	-0.0303	
252	Monday, April 04, 2011	**0.0981**	**0.1001**	-0.0370	**0.1431**	**0.1001**	-0.0280	**0.1097**	**0.1001**	Erratic	-0.0325	
476	Monday, November 14, 2011	**0.0987**	**0.1008**	-0.0380	**0.1434**	**0.1008**	-0.0320	**0.1095**	**0.1008**	-0.0340	-0.0347	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/26/10

Material: Mix 13.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.60**	**78.46**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.650**	**124.370**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.510**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5300**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.0**	

Reviewed By: Robert Varner, P.E. 7/26/2010

Burns Cooley Dennis, Inc - State Study No. 231

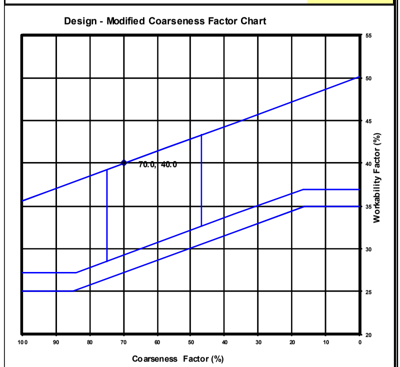
Customer: **MDOT** | Project: **090594** | MIX **14.0**

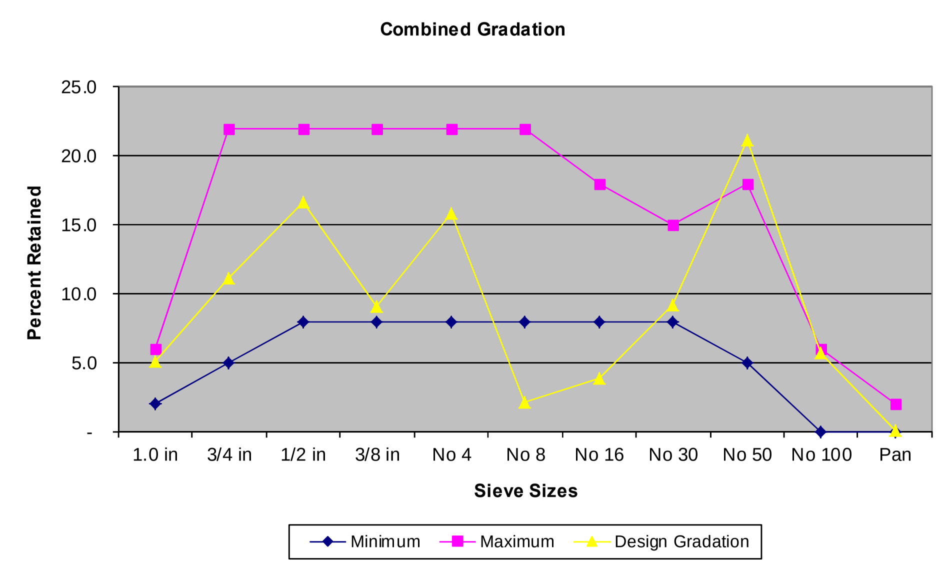
MIX NUMBER MM09 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM09

Date: 7/26/2010 | f'c: 4,000 psi | Design w/c ratio 0.450 | Size(c.f.): 1.25 | Factor: 0.05

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0030	13.00
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	5.0600	2.4770	2.200%	3.59	-	-2.200%	-0.16	1.0040	155.2540	7.1880	7.1880	7.18
3/4 in	5.0	22.0	11.1300	2.4770	2.200%	7.91	-	-2.200%	-0.35	2.2090	341.4980	15.8100	15.8100	15.82
1/2 in	8.0	22.0	16.6900	2.4770	2.200%	11.85	-	-2.200%	-0.52	3.3130	512.0940	23.7080	23.7080	23.71
3/8 in	8.0	22.0	9.1300	2.4770	2.200%	6.48	-	-2.200%	-0.29	1.8120	280.1330	12.9690	12.9690	12.97
No 4	8.0	22.0	15.8400	2.4880	2.200%	11.30	-	-2.200%	-0.50	3.1440	488.1720	22.6010	22.6010	22.6
No 8	8.0	22.0	2.1600	2.4880	2.200%	1.54	-	-2.200%	-0.07	0.4290	66.5690	3.0820	3.0820	3.08
No 16	8.0	18.0	3.8600	2.6280	0.260%	2.91	-	-0.260%	-0.02	0.7660	125.6550	5.8170	5.8170	5.82
No 30	8.0	15.0	9.2000	2.6280	0.260%	6.93	-	-0.260%	-0.04	1.8260	299.4890	13.8650	13.8650	13.87
No 50	5.0	18.0	21.1600	2.6280	0.260%	15.94	-	-0.260%	-0.08	4.2000	688.8240	31.8900	31.8900	31.89
No 100	-	6.0	5.7000	2.6280	0.260%	4.30	-	-0.260%	-0.02	1.1320	185.5530	8.5900	8.5900	8.59
Pan	-	2.0	0.0900	2.5370	1.420%	0.07	-	-1.420%	0.00	0.0180	2.8280	0.1310	0.1310	0.13
Total Grad%			100.0			72.83			-2.04	27.0020	3909.3490	180.9880	183.0240	183.0300

Fineness Mod			0.78
Q	23.0	72.0	42.0
I	16.0	44.0	18.0
W	21.0	59.0	40.0
CF Actual	52.4	69.6	70.0
WF Actual			40.0
AWF	23.3	48.7	39.00





Comments / Notes / Observations

Mix 14 - Manufactured Blend; 70/40

Pan Blend = 0.05, 0.07, 0.01, respectively

Mix Percent by Weight	
No. 57	42.00
No. 8	18.00
Sand	40.00
Combined Gravity Dry	2.5370
Combined Absorption	1.4200

Workability Measurements		
Workability Index	3.9	inches
Pre Vib Slump	2.0	inches
Post Vib.Slump	5.0	inches
Spread Length	10.75	inches
Spread Width	10.125	inches

Strength Test Results

Date	AGE (4x8 CYLINDERS)	psi	Avg. psi
07/27/10	1	1920	1910
	1	1900	
08/02/10	7	4210	4020
	7	3830	
08/09/10	14	4070	4260
	14	4450	
08/23/10	28	4950	4813
	28	4570	
	28	4920	
09/20/10	56	5020	5055
	56	5090	

Technician who conducted tests:

Plastic Test Results

Batch Time	9:34 AM	% Air	4.25	Unit Wt w/o Air	148.49	Design w/c	0.450
Sample Time	9:43 AM	Bucket Weight	5.40	Unit Wt (pcf)	144.68	Actual w/c	0.450
Air Temp.	75.2	Bucket Full	41.57	Theorectial Air	2.57	Design Unit Wt	144.78
Mix Temp.	72.9	Bucket Volume	0.250	Yield	1.27	Fine/Coarse	0.71
Slump, in.	2.5	Paste Volume (%)	23.69	Relative Yield	1.01	Bag Factor	5.60

Reviewed by: Robert Varner, P.E. 7/27/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 14.0
Mix Date Monday, July 26, 2010 Mix Time: 9:34 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8155	0.8165	11.67930	1.6320	10.0473
2	10.0000	0.8145	0.8155	11.65770	1.6300	10.0277
3	10.0000	0.8135	0.8160	11.62355	1.6295	9.9941

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	**Specimen 1**	**Reference Bar 1**	**Δ Length 1**	**Specimen 2**	**Reference Bar 2**	**Δ Length 2**	**Specimen 3**	**Reference Bar 3**	**Δ Length 3**	**Average**	
Specimen Age	**Test date**	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Tuesday, July 27, 2010	**0.1550**	**0.1003**	0.0547	**0.1330**	**0.1004**	0.0326	**0.0998**	**0.1004**	-0.0006	0.0289	**M/Rm**

		LENGTH CHANGE CALCULATIONS										
		Specimen 1	**Reference Bar 1**	**Δ Length 1**	**Specimen 2**	**Reference Bar 2**	**Δ Length 2**	**Specimen 3**	**Reference Bar 3**	**Δ Length 3**	**Average**	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Monday, August 23, 2010	**0.1552**	**0.1001**	0.0040	**0.1334**	**0.1001**	Erratic	**0.0998**	**0.1001**	0.0030	0.0035	**Soak**
32	Friday, August 27, 2010	**0.1548**	**0.1001**	0.0000	**0.1329**	**0.1001**	Erratic	**0.0994**	**0.1001**	-0.0010	-0.0005	**Shrinkage Room**
35	Monday, August 30, 2010	**0.1543**	**0.1001**	-0.0050	**0.1326**	**0.1001**	Erratic	**0.0991**	**0.1001**	-0.0040	-0.0045	
42	Monday, September 06, 2010	**0.1537**	**0.1001**	-0.0110	**0.1320**	**0.1001**	Erratic	**0.0984**	**0.1001**	-0.0110	-0.0110	
56	Monday, September 20, 2010	**0.1528**	**0.0996**	-0.0150	**0.1312**	**0.0996**	Erratic	**0.0975**	**0.0996**	-0.0150	-0.0150	
84	Monday, October 18, 2010	**0.1523**	**0.1000**	-0.0240	**0.1308**	**0.1000**	Erratic	**0.0971**	**0.1000**	-0.0230	-0.0235	
140	Monday, December 13, 2010	**0.1529**	**0.1012**	-0.0300	**0.1312**	**0.1012**	Erratic	**0.0973**	**0.1012**	-0.0330	-0.0315	
252	Monday, April 04, 2011	**0.1516**	**0.1001**	-0.0320	**0.1301**	**0.1001**	Erratic	**0.0960**	**0.1001**	-0.0350	-0.0335	
476	Monday, November 14, 2011	**0.1520**	**0.1007**	-0.0340	**0.1306**	**0.1007**	Erratic	**0.0963**	**0.1007**	-0.0380	-0.0360	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varmer, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/26/10

Material: Mix 14.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.85**	**79.35**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**125.150**	**126.150**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**125.650**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5370**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.5**	

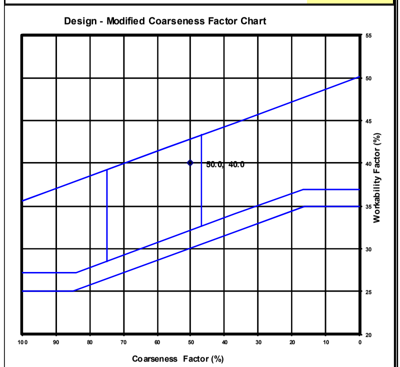
Reviewed By: Robert Varner, P.E. 7/27/2010

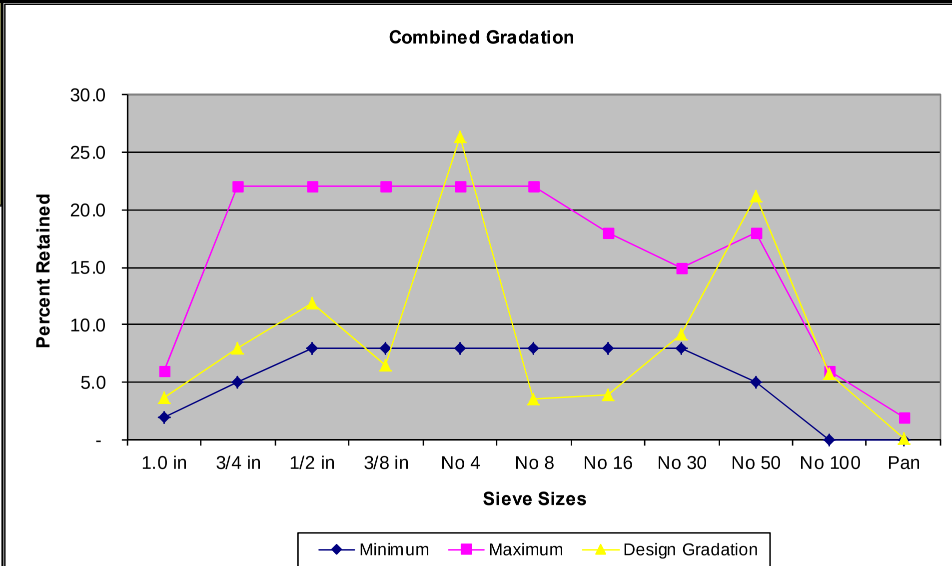
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594
MIX NUMBER	MM10	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks
MIX 15.0	Set #: MM10		
Date: 7/27/2010	f'c: 4,000 psi	Design w/c ratio 0.450	Size(c.f.): 1.25
Factor: 0.05			

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorption	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0050	13.00
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	3.6200	2.4770	2.200%	2.57	-	-2.200%	-0.11	0.7190	111.0710	5.1420	5.1420	5.15
3/4 in	5.0	22.0	7.9500	2.4770	2.200%	5.65	-	-2.200%	-0.25	1.5780	243.9270	11.2930	11.2930	11.31
1/2 in	8.0	22.0	11.9200	2.4770	2.200%	8.47	-	-2.200%	-0.37	2.3660	365.7370	16.9320	16.9320	16.93
3/8 in	8.0	22.0	6.5200	2.4770	2.200%	4.63	-	-2.200%	-0.20	1.2940	200.0510	9.2620	9.2620	9.26
No 4	8.0	22.0	26.4000	2.4880	2.200%	18.83	-	-2.200%	-0.83	5.2410	813.6190	37.6680	37.6680	37.67
No 8	8.0	22.0	3.6000	2.4880	2.200%	2.57	-	-2.200%	-0.11	0.7150	110.9480	5.1360	5.1360	5.14
No 16	8.0	18.0	3.8600	2.6280	0.260%	2.91	-	-0.260%	-0.02	0.7660	125.6550	5.8170	5.8170	5.82
No 30	8.0	15.0	9.2000	2.6280	0.260%	6.93	-	-0.260%	-0.04	1.8260	299.4890	13.8650	13.8650	13.87
No 50	5.0	18.0	21.1600	2.6280	0.260%	15.94	-	-0.260%	-0.08	4.2000	688.8240	31.8900	31.8900	31.89
No 100	-	6.0	5.7000	2.6280	0.260%	4.30	-	-0.260%	-0.02	1.1320	185.5530	8.5900	8.5900	8.59
Pan	-	2.0	0.0900	2.5390	1.420%	0.07	-	-1.420%	0.00	0.0180	2.8310	0.1310	0.1310	0.13
Total Grad%			100.0			72.86			-2.04	27.0040	3910.9850	181.0630	183.1010	183.1300

Fineness Mod			0.84
Q	23.0	72.0	30.0
I	16.0	44.0	30.0
W	21.0	59.0	40.0
CF Actual	52.4	69.6	50.0
WF Actual			40.0
AWF	23.4	48.6	39.00





Plastic Test Results

Batch Time	9:26 AM	% Air	4.00	Unit Wt w/o Air	148.54	Design w/c	0.450
Sample Time	9:35 AM	Bucket Weight	5.40	Unit Wt (pcf)	144.08	Actual w/c	0.450
Air Temp.	74.0	Bucket Full	41.42	Theorectial Air	3.00	Design Unit Wt	144.83
Mix Temp.	71.5	Bucket Volume	0.250	Yield	1.27	Fine/Coarse	0.71
Slump, in.	2.75	Paste Volume (%)	23.58	Relative Yield	1.02	Bag Factor	5.60

Comments / Notes / Observations

Mix 15 - Manufactured Blend; 50/40

Pan Blend = 0.05, 0.07, 0.01, respectively

Mix Percent by Weight	
No. 57	30.00
No. 8	30.00
Sand	40.00
Combined Gravity Dry	2.5300
Combined Absorption	1.4200

Workability Measurements		
Workability Index	8.5	inches
Pre Vib Slump	2.50	inches
Post Vib.Slump	8.25	inches
Spread Length	14.875	inches
Spread Width	13.625	inches

Strength Test Results

Date	AGE (4x8 CYLINDERS)	psi	Avg. psi
07/28/10	1	2380	2440
	1	2500	
08/03/10	7	4990	4980
	7	4970	
08/10/10	14	4450	4600
	14	4750	
08/24/10	28	4720	4433
	28	4040	
	28	4540	
09/21/10	56	5480	5565
	56	5650	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/27/2010

BURNS COOLEY DENNIS, INC.

GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 15.0

Mix Date Tuesday, July 27, 2010 Mix Time: 9:26 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8140	11.62925	1.6285	10.0008
2	10.0000	0.8165	0.8185	11.60825	1.6350	9.9733
3	10.0000	0.8160	0.8160	11.61140	1.6320	9.9794

SHRINKAGE TESTING - ASTM C157

INITIAL READINGS

	Gage Length (in.)	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
	10											
Specimen Age	**Test date**	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Wednesday, July 28, 2010	**0.1051**	**0.1004**	0.0047	**0.0830**	**0.1004**	-0.0174	**0.0883**	**0.1004**	-0.0121	-0.0083	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Tuesday, August 24, 2010	**0.1054**	**0.1001**	0.0060	**0.0834**	**0.1001**	0.0070	**0.0890**	**0.1001**	0.0100	0.0077	**Soak**
32	Saturday, August 28, 2010	**0.1051**	**0.1006**	-0.0020	**0.0831**	**0.1006**	-0.0010	**0.0885**	**0.1006**	0.0000	-0.0010	**Shrinkage Room**
35	Tuesday, August 31, 2010	**0.1045**	**0.1004**	-0.0060	**0.0826**	**0.1004**	-0.0040	**0.0880**	**0.1004**	-0.0030	-0.0043	
42	Tuesday, September 07, 2010	**0.1040**	**0.0999**	-0.0060	**0.0818**	**0.0999**	-0.0070	**0.0873**	**0.0999**	-0.0050	-0.0060	
56	Tuesday, September 21, 2010	**0.1034**	**0.0999**	-0.0120	**0.0813**	**0.0999**	-0.0120	**0.0866**	**0.0999**	-0.0120	-0.0120	
84	Tuesday, October 19, 2010	**0.1028**	**0.1000**	-0.0190	**0.0806**	**0.1000**	-0.0200	**0.0858**	**0.1000**	-0.0210	-0.0200	
140	Tuesday, December 14, 2010	**0.1031**	**0.1012**	-0.0280	**0.0810**	**0.1012**	-0.0280	**0.0861**	**0.1012**	-0.0300	-0.0287	
252	Tuesday, April 05, 2011	**0.1018**	**0.1001**	-0.0300	**0.0797**	**0.1001**	-0.0300	**0.0849**	**0.1001**	-0.0310	-0.0303	
476	Tuesday, November 15, 2011	**0.1022**	**0.1007**	-0.0320	**0.0800**	**0.1007**	-0.0330	**0.0853**	**0.1007**	-0.0330	-0.0327	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/27/10

Material: Mix 15.0 **Technician:** SB

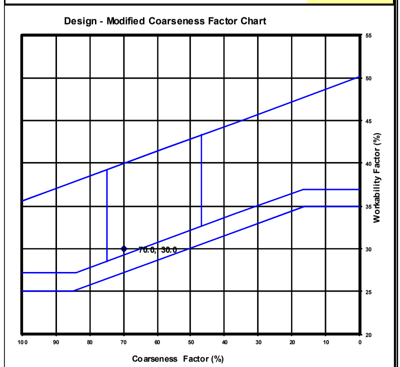
Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.65**	**78.55**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.750**	**124.550**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.650**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5300**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.9**	

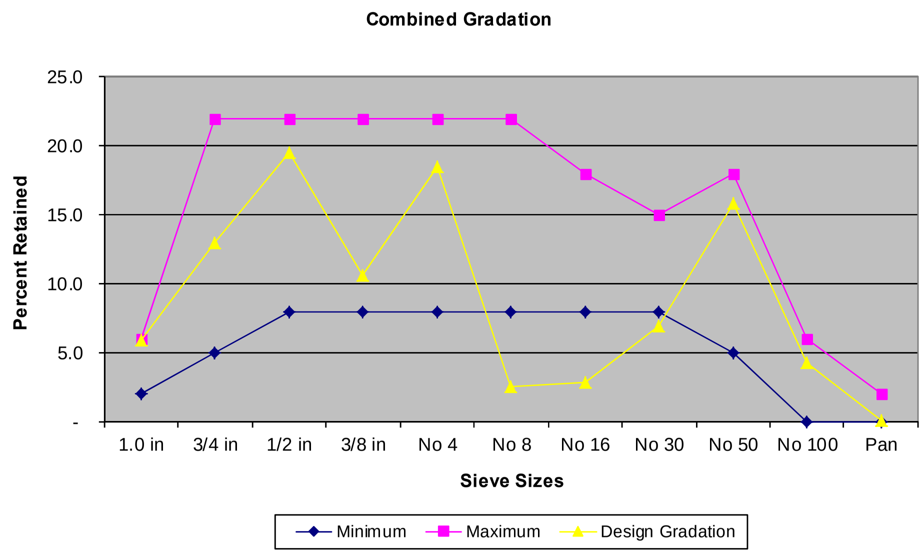
Reviewed By: Robert Varner, P.E. 7/27/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:		MDOT	Project:			090594						MIX	16.0	
MIX NUMBER	MM11		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks								Set #:	MM11	
MIX DESIGN INFO	Date:	7/27/2010		f'c:	4,000 psi		Design w/c ratio		0.450	Size(c.f.):	1.25	Factor:	0.05	
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.4550	12.46
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	5.9100	2.4770	2.200%	4.31	-	-2.200%	-0.19	1.2040	186.0850	8.6150	8.6150	8.64
3/4 in	5.0	22.0	12.9800	2.4770	2.200%	9.46	-	-2.200%	-0.42	2.6440	408.6930	18.9210	18.9210	18.91
1/2 in	8.0	22.0	19.4700	2.4770	2.200%	14.19	-	-2.200%	-0.62	3.9660	613.0400	28.3810	28.3810	28.38
3/8 in	8.0	22.0	10.6500	2.4770	2.200%	7.76	-	-2.200%	-0.34	2.1700	335.3300	15.5250	15.5250	15.53
No 4	8.0	22.0	18.4800	2.4880	2.200%	13.53	-	-2.200%	-0.60	3.7650	584.4530	27.0580	27.0580	27.06
No 8	8.0	22.0	2.5200	2.4880	2.200%	1.84	-	-2.200%	-0.08	0.5130	79.6980	3.6900	3.6900	3.69
No 16	8.0	18.0	2.8900	2.6280	0.260%	2.23	-	-0.260%	-0.01	0.5890	96.5430	4.4700	4.4700	4.47
No 30	8.0	15.0	6.9000	2.6280	0.260%	5.34	-	-0.260%	-0.03	1.4060	230.5000	10.6710	10.6710	10.67
No 50	5.0	18.0	15.8700	2.6280	0.260%	12.27	-	-0.260%	-0.06	3.2330	530.1510	24.5440	24.5440	24.54
No 100	-	6.0	4.2700	2.6280	0.260%	3.30	-	-0.260%	-0.02	0.8700	142.6430	6.6040	6.6040	6.6
Pan	-	2.0	0.0700	2.5230	1.620%	0.05	-	-1.620%	0.00	0.0140	2.2450	0.1040	0.1040	0.11
Total Grad%			100.0			74.29			-2.37	27.0030	3911.3260	181.0800	183.4500	183.4700

Fineness Mod			0.75
Q	23.0	72.0	49.0
I	16.0	44.0	21.0
W	21.0	59.0	30.0
CF Actual	#NUM!	#NUM!	70.0
WF Actual			30.0
AWF	23.3	48.7	27.87





Plastic Test Results

Batch Time	10:01 AM	% Air	2.50	Unit Wt w/o Air	148.56	Design w/c	0.450
Sample Time	10:10 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.80	Actual w/c	0.450
Air Temp.	74.9	Bucket Full	42.1	Theorectial Air	1.19	Design Unit Wt	144.85
Mix Temp.	71.5	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.45
Slump, in.	3.25	Paste Volume (%)	22.06	Relative Yield	1.00	Bag Factor	5.15

Comments / Notes / Observations

Mix 16 - Manufactured Blend; 70/30

Pan Blend = 0.04, 0.06, 0.01

Mix Percent by Weight

No. 57	49.00
No. 8	21.00
Sand	30.00
Combined Gravity Dry	2.5230
Combined Absorption	1.6200

Workability Measurements

Workability Index	5.2	inches
Pre Vib Slump	2.0	inches
Post Vib.Slump	5.0	inches
Spread Length	12.50	inches
Spread Width	12.00	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/28/10	1	2260	2275
	1	2290	
08/03/10	7	4230	4125
	7	4020	
08/10/10	14	4660	4685
	14	4710	
08/24/10	28	4980	4960
	28	5270	
	28	4630	
09/21/10	56	5590	5405
	56	5220	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/27/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 16.0
Mix Date: Tuesday, July 27, 2010
Mix Time: 10:01 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8140	0.8155	11.62900	1.6295	9.9995
2	10.0000	0.8185	0.8180	11.64090	1.6365	10.0044
3	10.0000	0.8140	0.8155	11.71635	1.6295	10.0869

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
Specimen Age	**Test date**	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Wednesday, July 28, 2010	**0.1035**	**0.1003**	0.0032	**0.1156**	**0.1003**	0.0153	**0.1912**	**0.1003**	0.0909	0.0365	**M/Rm**
		LENGTH CHANGE CALCULATIONS										
		Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Tuesday, August 24, 2010	**0.1038**	**0.1001**	0.0050	**0.1158**	**0.1001**	0.0040	**0.1926**	**0.1001**	0.0160	0.0083	**Soak**
32	Saturday, August 28, 2010	**0.1035**	**0.1006**	-0.0030	**0.1156**	**0.1006**	-0.0030	**0.1922**	**0.1006**	0.0070	0.0003	**Shrinkage Room**
35	Tuesday, August 31, 2010	**0.1029**	**0.1004**	-0.0070	**0.1152**	**0.1004**	-0.0050	**0.1917**	**0.1004**	0.0040	-0.0027	
42	Tuesday, September 07, 2010	**0.1024**	**0.0999**	-0.0070	**0.1144**	**0.0999**	-0.0080	**0.1911**	**0.0999**	0.0030	-0.0040	
56	Tuesday, September 21, 2010	**0.1020**	**0.0999**	-0.0110	**0.1140**	**0.0999**	-0.0120	**0.1906**	**0.0999**	-0.0020	-0.0083	
84	Tuesday, October 19, 2010	**0.1013**	**0.1000**	-0.0190	**0.1134**	**0.1000**	-0.0190	**0.1899**	**0.1000**	-0.0100	-0.0160	
140	Tuesday, December 14, 2010	**0.1021**	**0.1012**	-0.0230	**0.1141**	**0.1012**	-0.0240	**0.1902**	**0.1012**	-0.0190	-0.0220	
252	Tuesday, April 05, 2011	**0.1011**	**0.1001**	-0.0220	**0.1129**	**0.1001**	-0.0250	**0.1892**	**0.1001**	-0.0180	-0.0217	
476	Tuesday, November 15, 2011	**0.1015**	**0.1007**	-0.0240	**0.1134**	**0.1007**	-0.0260	**0.1897**	**0.1007**	-0.0190	-0.0230	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/27/10

Material: Mix 16.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.33**	**79.11**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.110**	**125.670**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.890**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5230**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.5**	

Reviewed By: Robert Varner, P.E. 7/27/2010

Burns Cooley Dennis, Inc - State Study No. 231

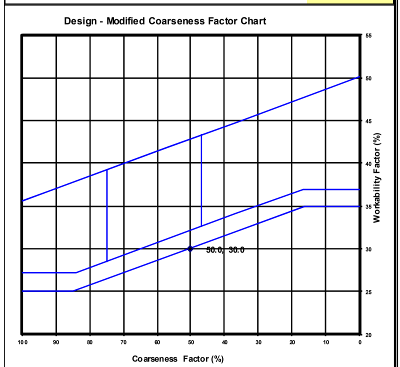
Customer: **MDOT** | Project: **090594** | MIX **17.0**

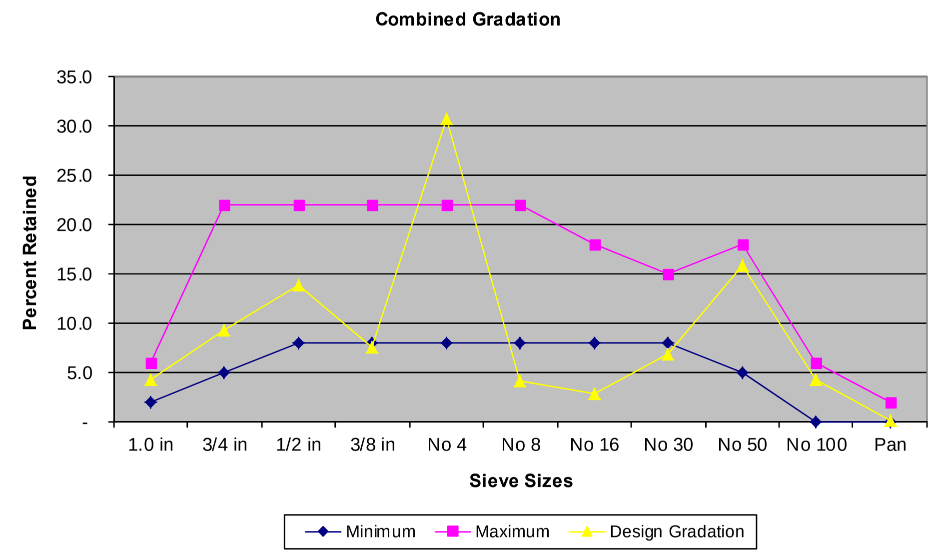
MIX NUMBER MM12 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM12

MIX DESIGN INFO | Date: 7/29/2010 | f'c: 4,000 psi | Design w/c ratio 0.450 | Size(c.f.): 1.25 | Factor: 0.05

Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorption	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.4570	12.46
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	4.2200	2.4770	2.200%	3.08	-	-2.200%	-0.14	0.8600	132.8730	6.1520	6.1520	6.15
3/4 in	5.0	22.0	9.2700	2.4770	2.200%	6.76	-	-2.200%	-0.30	1.8880	291.8790	13.5130	13.5130	13.52
1/2 in	8.0	22.0	13.9100	2.4770	2.200%	10.14	-	-2.200%	-0.45	2.8340	437.9760	20.2770	20.2770	20.28
3/8 in	8.0	22.0	7.6000	2.4770	2.200%	5.54	-	-2.200%	-0.24	1.5480	239.2970	11.0790	11.0790	11.08
No 4	8.0	22.0	30.8000	2.4880	2.200%	22.55	-	-2.200%	-0.99	6.2740	974.0880	45.0970	45.0970	45.1
No 8	8.0	22.0	4.2000	2.4880	2.200%	3.07	-	-2.200%	-0.14	0.8560	132.8300	6.1500	6.1500	6.15
No 16	8.0	18.0	2.8900	2.6280	0.260%	2.23	-	-0.260%	-0.01	0.5890	96.5430	4.4700	4.4700	4.47
No 30	8.0	15.0	6.9000	2.6280	0.260%	5.34	-	-0.260%	-0.03	1.4060	230.5000	10.6710	10.6710	10.67
No 50	5.0	18.0	15.8700	2.6280	0.260%	12.27	-	-0.260%	-0.06	3.2330	530.1510	24.5440	24.5440	24.54
No 100	-	6.0	4.2700	2.6280	0.260%	3.30	-	-0.260%	-0.02	0.8700	142.6430	6.6040	6.6040	6.6
Pan	-	2.0	0.0700	2.5240	1.620%	0.05	-	-1.620%	0.00	0.0140	2.2460	0.1040	0.1040	0.11
Total Grad%			100.0			74.33			-2.37	27.0010	3912.9710	181.1580	183.5300	183.5400

Fineness Mod			0.82
Q	23.0	72.0	35.0
I	16.0	44.0	35.0
W	21.0	59.0	30.0
CF Actual	#NUM!	#NUM!	50.0
WF Actual			30.0
AWF	23.4	48.6	27.88





Plastic Test Results

Batch Time	9:58 AM	% Air	3.00	Unit Wt w/o Air	148.64	Design w/c	0.450
Sample Time	10:07 AM	Bucket Weight	5.40	Unit Wt (pcf)	147.00	Actual w/c	0.450
Air Temp.	72.0	Bucket Full	42.15	Theorectial Air	1.10	Design Unit Wt	144.92
Mix Temp.	69.5	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.45
Slump, in.	3.00	Paste Volume (%)	22.08	Relative Yield	1.00	Bag Factor	5.15

Comments / Notes / Observations

Mix 17 - Manufactured Blend; 50/30

Pan Blend = 0.4, 0.4, 0.3

Mix Percent by Weight	
No. 57	35.00
No. 8	35.00
Sand	30.00
Combined Gravity Dry	2.5240
Combined Absorption	1.6200

Workability Measurements		
Workability Index	6.6	inches
Pre Vib Slump	2.25	inches
Post Vib.Slump	6.5	inches
Spread Length	13.75	inches
Spread Width	12.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/30/10	1	2230	2215
	1	2200	
08/05/10	7	4580	4455
	7	4330	
08/12/10	14	5220	5135
	14	5050	
08/26/10	28	4950	5170
	28	5060	
	28	5500	
09/23/10	56	5720	5640
	56	5560	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/29/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 17.0
Mix Date: Thursday, July 29, 2010 Mix Time: 9:58 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8160	0.8155	11.62070	1.6315	9.9892
2	10.0000	0.8145	0.8175	11.60460	1.6320	9.9726
3	10.0000	0.8185	0.8145	11.60420	1.6330	9.9712

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Friday, July 30, 2010	**0.0973**	**0.1004**	-0.0031	**0.0812**	**0.1004**	-0.0192	**0.0819**	**0.1004**	-0.0185	-0.0136	M/Rm

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Thursday, August 26, 2010	**0.0981**	**0.1001**	0.0110	**0.0824**	**0.1001**	0.0150	**0.0823**	**0.1001**	0.0070	0.0110	Soak
32	Monday, August 30, 2010	No record	No record	No record	No record	No record	No record	No record	No record	No record	No record	Shrinkage Room
35	Thursday, September 02, 2010	No record	No record	No record	No record	No record	No record	No record	No record	No record	No record	
48	Wednesday, September 15, 2010	**0.0961**	**0.0999**	-0.0070	**0.0803**	**0.0999**	-0.0040	**0.0805**	**0.0999**	-0.0090	-0.0067	
56	Thursday, September 23, 2010	**0.0957**	**0.0998**	-0.0100	**0.0797**	**0.0998**	-0.0090	**0.0800**	**0.0998**	-0.0130	-0.0107	
84	Thursday, October 21, 2010	**0.0950**	**0.0998**	-0.0170	**0.0791**	**0.0998**	-0.0150	**0.0794**	**0.0998**	-0.0190	-0.0170	
140	Thursday, December 16, 2010	**0.0951**	**0.1005**	-0.0230	**0.0792**	**0.1005**	-0.0210	**0.0795**	**0.1005**	-0.0250	-0.0230	
252	Thursday, April 07, 2011	**0.0946**	**0.1002**	-0.0250	**0.0787**	**0.1002**	-0.0230	**0.0790**	**0.1002**	-0.0270	-0.0250	
476	Thursday, November 17, 2011	**0.0950**	**0.1008**	-0.0270	**0.0788**	**0.1008**	-0.0280	**0.0793**	**0.1008**	-0.0300	-0.0283	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/29/10

Material: Mix 17.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**77.87**	**78.26**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.190**	**123.970**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.580**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5240**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.4**	

Reviewed By: Robert Varner, P.E. 7/29/2010

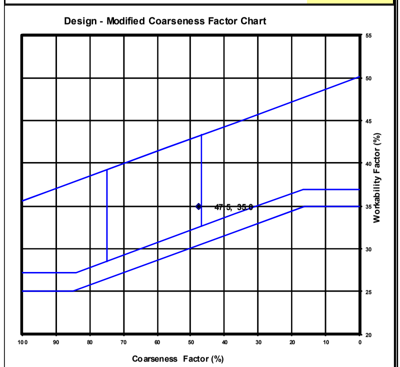
Burns Cooley Dennis, Inc - State Study No. 231

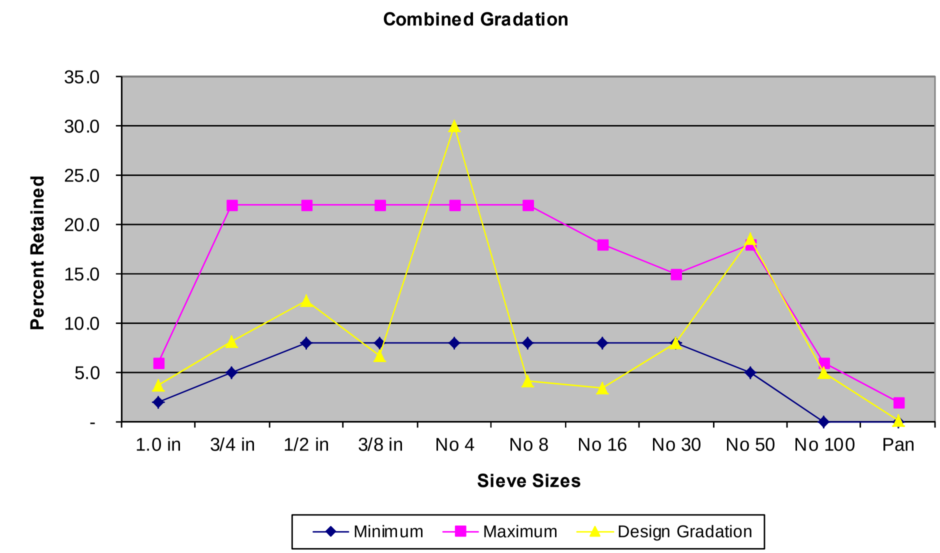
Customer: **MDOT** | Project: **090594** | MIX **18.0**

MIX NUMBER MM13 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM13

MIX DESIGN INFO	Date:	7/28/2010		f'c:	4,000 psi	Design w/c ratio		0.450		Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.1420	13.14
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	3.7200	2.4770	2.200%	2.64	-	-2.200%	-0.12	0.7380	114.1390	5.2840	5.2840	5.29
3/4 in	5.0	22.0	8.1800	2.4770	2.200%	5.81	-	-2.200%	-0.26	1.6240	250.9840	11.6200	11.6200	11.62
1/2 in	8.0	22.0	12.2700	2.4770	2.200%	8.71	-	-2.200%	-0.38	2.4360	376.4760	17.4290	17.4290	17.44
3/8 in	8.0	22.0	6.7100	2.4770	2.200%	4.77	-	-2.200%	-0.21	1.3320	205.8810	9.5320	9.5320	9.53
No 4	8.0	22.0	30.0300	2.4880	2.200%	21.42	-	-2.200%	-0.94	5.9610	925.4920	42.8470	42.8470	42.85
No 8	8.0	22.0	4.1000	2.4880	2.200%	2.92	-	-2.200%	-0.13	0.8140	126.3580	5.8500	5.8500	5.85
No 16	8.0	18.0	3.3700	2.6280	0.260%	2.54	-	-0.260%	-0.01	0.6690	109.7040	5.0790	5.0790	5.08
No 30	8.0	15.0	8.0500	2.6280	0.260%	6.07	-	-0.260%	-0.03	1.5980	262.0520	12.1320	12.1320	12.13
No 50	5.0	18.0	18.5200	2.6280	0.260%	13.96	-	-0.260%	-0.07	3.6760	602.8830	27.9110	27.9110	27.91
No 100	-	6.0	4.9800	2.6280	0.260%	3.75	-	-0.260%	-0.02	0.9890	162.1140	7.5050	7.5050	7.51
Pan	-	2.0	0.0800	2.5320	1.520%	0.06	-	-1.520%	0.00	0.0160	2.5090	0.1160	0.1160	0.12
Total Grad%			100.0			72.65			-2.17	27.0020	3901.8720	180.6420	182.8170	182.8400

Fineness Mod			0.84
Q	23.0	72.0	30.9
I	16.0	44.0	34.1
W	21.0	59.0	35.0
CF Actual	49.7	72.3	47.5
WF Actual			35.0
AWF	23.7	48.3	34.00





Plastic Test Results

Batch Time	9:28 AM	% Air	3.00	Unit Wt w/o Air	148.21	Design w/c	0.450
Sample Time	9:37 AM	Bucket Weight	5.40	Unit Wt (pcf)	145.80	Actual w/c	0.450
Air Temp.	71.8	Bucket Full	41.85	Theorectial Air	1.62	Design Unit Wt	144.50
Mix Temp.	69.5	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.57
Slump, in.	3.5	Paste Volume (%)	23.90	Relative Yield	1.00	Bag Factor	5.60

Comments / Notes / Observations

Mix 18 - Manufactured Blend; 47.5/35

Pan Blend = 0.04, 0.04, 0.04,

Mix Percent by Weight	
No. 57	30.90
No. 8	34.10
Sand	35.00
Combined Gravity Dry	2.5320
Combined Absorption	1.5200

Workability Measurements		
Workability Index	8.4	inches
Pre Vib Slump	2.50	inches
Post Vib.Slump	7.25	inches
Spread Length	15.25	inches
Spread Width	14.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/29/10	1	2200	2280
	1	2360	
08/04/10	7	3830	4000
	7	4170	
08/11/10	14	4510	4280
	14	4050	
08/25/10	28	4710	4900
	28	4810	
	28	5180	
09/22/10	56	5390	5470
	56	5550	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 7/30/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 18.0
Mix Date: Wednesday, July 28, 2010 Mix Time: 9:28 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8135	0.8170	11.61505	1.6305	9.9846
2	10.0000	0.8185	0.8175	11.62250	1.6360	9.9865
3	10.0000	0.8130	0.8160	11.59650	1.6290	9.9675

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Thursday, July 29, 2010	**0.0913**	**0.1004**	-0.0091	**0.0989**	**0.1004**	-0.0015	**0.0708**	**0.1004**	-0.0296	-0.0134	M/Rm

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Wednesday, August 25, 2010	**0.0918**	**0.1001**	0.0080	**0.0996**	**0.1001**	0.0100	**0.0713**	**0.1001**	0.0080	0.0087	Soak
32	Sunday, August 29, 2010	**0.0910**	**0.1001**	0.0000	**0.0988**	**0.1001**	0.0020	**0.0705**	**0.1001**	0.0000	0.0007	Shrinkage Room
35	Wednesday, September 01, 2010	**0.0910**	**0.1002**	-0.0010	**0.0988**	**0.1002**	0.0010	**0.0703**	**0.1002**	-0.0030	-0.0010	
42	Wednesday, September 08, 2010	**0.0904**	**0.0999**	-0.0040	**0.0981**	**0.1000**	-0.0040	**0.0698**	**0.1000**	-0.0060	-0.0047	
56	Wednesday, September 22, 2010	**0.0896**	**0.0998**	-0.0110	**0.0973**	**0.0998**	-0.0100	**0.0691**	**0.0998**	-0.0110	-0.0107	
84	Wednesday, October 20, 2010	**0.0888**	**0.0998**	-0.0190	**0.0966**	**0.0998**	-0.0170	**0.0683**	**0.0998**	-0.0190	-0.0183	
140	Wednesday, December 15, 2010	**0.0894**	**0.1012**	-0.0270	**0.0974**	**0.1011**	-0.0220	**0.0689**	**0.1011**	-0.0260	-0.0250	
252	Wednesday, April 06, 2011	**0.0879**	**0.1001**	-0.0310	**0.0959**	**0.1001**	-0.0270	**0.0679**	**0.1001**	-0.0260	-0.0280	
476	Wednesday, November 16, 2011	**0.0885**	**0.1008**	-0.0320	**0.0963**	**0.1008**	-0.0300	**0.0681**	**0.1007**	-0.0300	-0.0307	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 07/28/10

Material: Mix 18.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**77.72**	**78.65**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**122.890**	**124.750**

Void Content	
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.820**
Bulk Dry Specific Gravity of Aggregate, S	**2.5320**
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**
Void Content, % = 100[(S*W)-M]/(S*W)	**21.5**

Reviewed By: Robert Varner, P.E. 7/30/2010

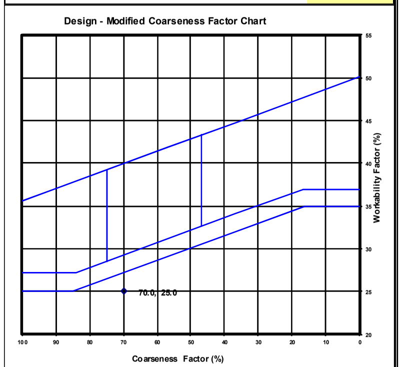
Burns Cooley Dennis, Inc - State Study No. 231

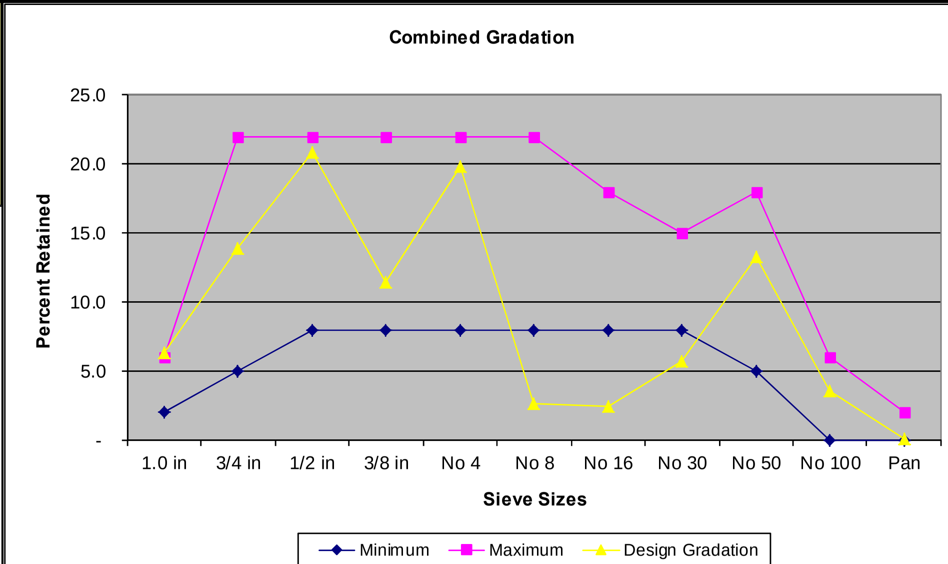
Customer: **MDOT** | Project: **090594** | MIX **19.0**

MIX NUMBER MM14 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM14

MIX DESIGN INFO	Date: 7/29/2010			f'c: 4,000 psi			Design w/c ratio 0.450			Size(c.f.): 1.25		Factor: 0.05	
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.5950	12.6
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	6.3300	2.4770	2.200%	4.61	-	-2.200%	-0.20	1.2890	199.3090	9.2270	9.2270	9.24
3/4 in	5.0	22.0	13.9100	2.4770	2.200%	10.14	-	-2.200%	-0.45	2.8340	437.9760	20.2770	20.2770	20.28
1/2 in	8.0	22.0	20.8600	2.4770	2.200%	15.20	-	-2.200%	-0.67	4.2490	656.8060	30.4080	30.4080	30.42
3/8 in	8.0	22.0	11.4100	2.4770	2.200%	8.32	-	-2.200%	-0.37	2.3240	359.2600	16.6320	16.6320	16.63
No 4	8.0	22.0	19.8000	2.4880	2.200%	14.50	-	-2.200%	-0.64	4.0330	626.1990	28.9910	28.9910	28.99
No 8	8.0	22.0	2.7000	2.4880	2.200%	1.98	-	-2.200%	-0.09	0.5500	85.3910	3.9530	3.9530	3.95
No 16	8.0	18.0	2.4100	2.6280	0.260%	1.86	-	-0.260%	-0.01	0.4910	80.5080	3.7270	3.7270	3.73
No 30	8.0	15.0	5.7500	2.6280	0.260%	4.45	-	-0.260%	-0.02	1.1710	192.0840	8.8930	8.8930	8.89
No 50	5.0	18.0	13.2300	2.6280	0.260%	10.23	-	-0.260%	-0.05	2.6950	441.9590	20.4610	20.4610	20.46
No 100	-	6.0	3.5600	2.6280	0.260%	2.75	-	-0.260%	-0.01	0.7250	118.9250	5.5060	5.5060	5.51
Pan	-	2.0	0.0500	2.5160	1.720%	0.04	-	-1.720%	0.00	0.0100	1.5990	0.0740	0.0740	0.08
Total Grad%			100.0			74.07			-2.51	27.0000	3901.9610	180.6460	183.1560	183.1900

Fineness Mod			0.73
Q	23.0	72.0	52.5
I	16.0	44.0	22.5
W	21.0	59.0	25.0
CF Actual	#NUM!	#NUM!	70.0
WF Actual			25.0
AWF	23.3	48.7	22.87





Comments / Notes / Observations

Mix 19 - Manufactured Blend; 70/25

Pan Blend = 0.04, 0.02, 0.02

Mix Percent by Weight	
No. 57	52.50
No. 8	22.50
Sand	25.00
Combined Gravity Dry	2.5160
Combined Absorption	1.7200

Workability Measurements		
Workability Index	6.7	inches
Pre Vib Slump	3.25	inches
Post Vib.Slump	7.0	inches
Spread Length	13.50	inches
Spread Width	13.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
07/30/10	1	2100	2155
	1	2210	
08/05/10	7	4820	4725
	7	4630	
08/12/10	14	5170	5195
	14	5220	
08/26/10	28	5470	5603
	28	5620	
	28	5720	
09/23/10	56	6260	6145
	56	6030	

Technician who conducted tests:

Plastic Test Results

Batch Time	10:34 AM	% Air	1.75	Unit Wt w/o Air	148.22	Design w/c	0.450
Sample Time	10:43 AM	Bucket Weight	5.40	Unit Wt (pcf)	148.00	Actual w/c	0.450
Air Temp.	72.2	Bucket Full	42.4	Theorectial Air	0.15	Design Unit Wt	144.52
Mix Temp.	69.5	Bucket Volume	0.250	Yield	1.24	Fine/Coarse	0.35
Slump, in.	3.00	Paste Volume (%)	22.27	Relative Yield	0.99	Bag Factor	5.15

Reviewed by: Robert Varner, P.E. 7/30/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 19.0

Mix Date: Thursday, July 29, 2010 Mix Time: 10:34 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8130	0.8120	11.58825	1.6250	9.9633
2	10.0000	0.8140	0.8105	11.61945	1.6245	9.9950
3	10.0000	0.8140	0.8150	11.60095	1.6290	9.9720

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Friday, July 30, 2010	**0.0640**	**0.1004**	-0.0364	**0.0974**	**0.1003**	-0.0029	**0.0764**	**0.1003**	-0.0239	-0.0211	M/Rm

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Thursday, August 26, 2010	**0.0646**	**0.1001**	0.0090	**0.0981**	**0.1001**	0.0090	**0.0774**	**0.1001**	0.0120	0.0100	Soak
32	Monday, August 30, 2010	No record	No record	No record	No record	No record	No record	No record	No record	No record	No record	Shrinkage Room
35	Thursday, September 02, 2010	No record	No record	No record	No record	No record	No record	No record	No record	No record	No record	
48	Wednesday, September 15, 2010	**0.0629**	**0.0999**	-0.0060	**0.0965**	**0.0999**	-0.0050	**0.0754**	**0.0999**	-0.0060	-0.0057	
56	Thursday, September 23, 2010	**0.0624**	**0.0998**	-0.0100	**0.0961**	**0.0998**	-0.0080	**0.0749**	**0.0998**	-0.0100	-0.0093	
84	Thursday, October 21, 2010	**0.0618**	**0.0998**	-0.0160	**0.0955**	**0.0998**	-0.0140	**0.0742**	**0.0998**	-0.0170	-0.0157	
140	Thursday, December 16, 2010	**0.0620**	**0.1005**	-0.0210	**0.0956**	**0.1005**	-0.0200	**0.0741**	**0.1005**	-0.0250	-0.0220	
252	Thursday, April 07, 2011	**0.0616**	**0.1002**	-0.0220	**0.0954**	**0.1002**	-0.0190	**0.0741**	**0.1002**	-0.0220	-0.0210	
476	Thursday, November 17, 2011	**0.0619**	**0.1008**	-0.0250	**0.0955**	**0.1008**	-0.0240	**0.0745**	**0.1008**	-0.0240	-0.0243	

Note: Lowest Reading Value Recorded.

Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (ASTM C 29)

Project: 090594 **Date:** 07/29/10

Material: Mix 19.0 **Technician:**

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**76.83**	**76.24**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**121.100**	**119.920**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**120.510**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5160**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**23.1**	

Reviewed By:

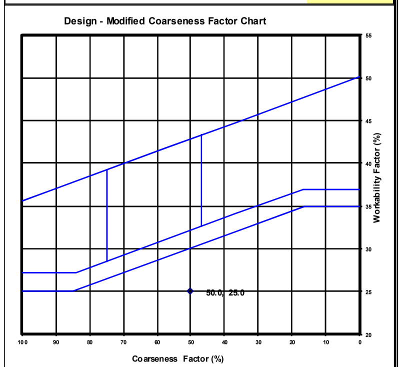
Burns Cooley Dennis, Inc - State Study No. 231

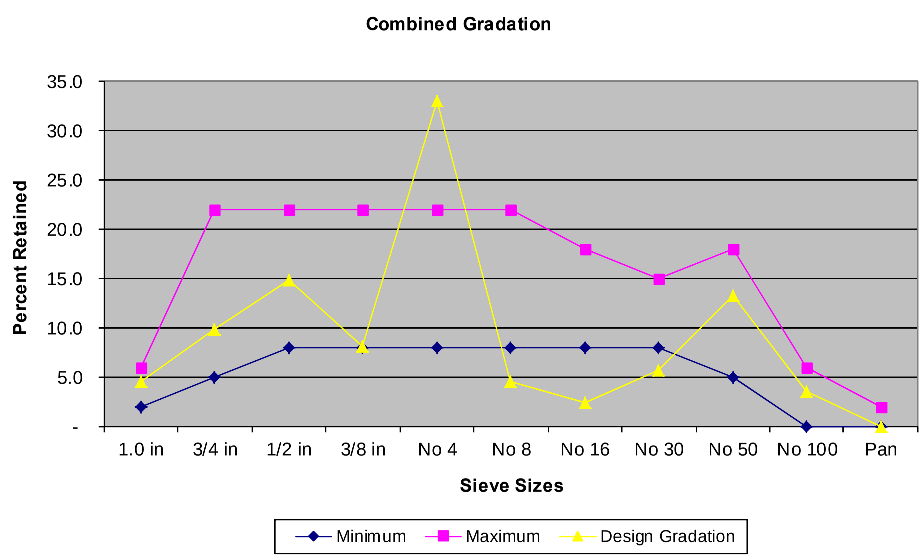
Customer: **MDOT** | Project: **090594** | MIX **20.0**

MIX NUMBER MM15 | **Notes:** Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM15

MIX DESIGN INFO	Date:	8/2/2010	f'c:	4,000 psi	Design w/c ratio	0.450			Size(c.f.):	1.25	Factor:	0.05	
Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorption	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.5970	12.6
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	4.5200	2.4770	2.200%	3.29	-	-2.200%	-0.14	0.9210	142.3190	6.5890	6.5890	6.6
3/4 in	5.0	22.0	9.9300	2.4770	2.200%	7.24	-	-2.200%	-0.32	2.0230	312.6600	14.4750	14.4750	14.49
1/2 in	8.0	22.0	14.9000	2.4770	2.200%	10.86	-	-2.200%	-0.48	3.0350	469.1470	21.7200	21.7200	21.72
3/8 in	8.0	22.0	8.1500	2.4770	2.200%	5.94	-	-2.200%	-0.26	1.6600	256.6140	11.8800	11.8800	11.88
No 4	8.0	22.0	32.9900	2.4880	2.200%	24.15	-	-2.200%	-1.06	6.7200	1043.3490	48.3030	48.3030	48.3
No 8	8.0	22.0	4.5100	2.4880	2.200%	3.30	-	-2.200%	-0.15	0.9190	142.6340	6.6030	6.6030	6.6
No 16	8.0	18.0	2.4100	2.6280	0.260%	1.86	-	-0.260%	-0.01	0.4910	80.5080	3.7270	3.7270	3.73
No 30	8.0	15.0	5.7500	2.6280	0.260%	4.45	-	-0.260%	-0.02	1.1710	192.0840	8.8930	8.8930	8.89
No 50	5.0	18.0	13.2300	2.6280	0.260%	10.23	-	-0.260%	-0.05	2.6950	441.9590	20.4610	20.4610	20.46
No 100	-	6.0	3.5600	2.6280	0.260%	2.75	-	-0.260%	-0.01	0.7250	118.9250	5.5060	5.5060	5.51
Pan	-	2.0	0.0500	2.5170	1.720%	0.04	-	-1.720%	0.00	0.0100	1.6000	0.0740	0.0740	0.08
Total Grad%			100.0			74.12			-2.51	26.9990	3903.7440	180.7280	183.2400	183.2700

Fineness Mod			0.81
Q	23.0	72.0	37.5
I	16.0	44.0	37.5
W	21.0	59.0	25.0
CF Actual	#NUM!	#NUM!	50.0
WF Actual			25.0
AWF	23.4	48.6	22.88





Plastic Test Results

Batch Time	9:37 AM	% Air	2.25	Unit Wt w/o Air	148.30	Design w/c	0.450
Sample Time	9:46 AM	Bucket Weight	5.40	Unit Wt (pcf)	147.40	Actual w/c	0.450
Air Temp.	72.5	Bucket Full	42.25	Theorectial Air	0.60	Design Unit Wt	144.59
Mix Temp.	70.5	Bucket Volume	0.250	Yield	1.24	Fine/Coarse	0.35
Slump, in.	2.75	Paste Volume (%)	22.17	Relative Yield	0.99	Bag Factor	5.15

Comments / Notes / Observations

Mix 20 - Manufactured Blend; 50/25

Pan Blend = 0.03, 0.03, 0.02

Mix Percent by Weight	
No. 57	37.50
No. 8	37.50
Sand	25.00
Combined Gravity Dry	2.5170
Combined Absorption	1.7200

Workability Measurements		
Workability Index	4.4	inches
Pre Vib Slump	2.0	inches
Post Vib.Slump	4.75	inches
Spread Length	11.75	inches
Spread Width	11.00	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/03/10	1	2450	2485
	1	2520	
08/09/10	7	4600	4585
	7	4570	
08/16/10	14	5080	5150
	14	5220	
08/30/10	28	6330	6093
	28	5680	
	28	6270	
09/27/10	56	6890	6575
	56	6260	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/2/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157
BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594
Mix Number Mix 20.0
Mix Date Monday, August 02, 2010 Mix Time: 9:37 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8150	0.8155	11.63930	1.6305	10.0088
2	10.0000	0.8120	0.8145	11.62655	1.6265	10.0001
3	10.0000	0.8160	0.8120	11.61070	1.6280	9.9827

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
Specimen Age	Test date	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Tuesday, August 03, 2010	**0.1169**	**0.1003**	0.0166	**0.1021**	**0.1003**	0.0018	**0.0872**	**0.1003**	-0.0131	0.0018	**M/Rm**
		LENGTH CHANGE CALCULATIONS										
		Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Monday, August 30, 2010	**0.1186**	**0.1001**	0.0190	**0.1028**	**0.1001**	0.0090	**0.0881**	**0.1001**	0.0110	0.0130	**Soak**
32	Friday, September 03, 2010	**0.1180**	**0.1001**	0.0130	**0.1022**	**0.1001**	0.0030	**0.0874**	**0.1001**	0.0040	0.0067	**Shrinkage Room**
35	Monday, September 06, 2010	**0.1176**	**0.1001**	0.0090	**0.1018**	**0.1001**	-0.0010	**0.0871**	**0.1001**	0.0010	0.0030	
42	Monday, September 13, 2010	**0.1170**	**0.0998**	0.0060	**0.1013**	**0.0998**	-0.0030	**0.0866**	**0.0998**	-0.0010	0.0007	
56	Monday, September 27, 2010	**0.1161**	**0.0996**	-0.0010	**0.1005**	**0.0996**	-0.0090	**0.0857**	**0.0996**	-0.0080	-0.0060	
84	Monday, October 25, 2010	**0.1165**	**0.1008**	-0.0090	**0.1012**	**0.1008**	-0.0140	**0.0862**	**0.1008**	-0.0150	-0.0127	
140	Monday, December 20, 2010	**0.1158**	**0.1007**	-0.0150	**0.1006**	**0.1007**	-0.0190	**0.0856**	**0.1007**	-0.0200	-0.0180	
252	Monday, April 11, 2011	**0.1153**	**0.1003**	-0.0160	**0.1001**	**0.1003**	-0.0200	**0.0852**	**0.1003**	-0.0200	-0.0187	
476	Monday, November 21, 2011	**0.1157**	**0.1008**	-0.0170	**0.1005**	**0.1008**	-0.0210	**0.0854**	**0.1008**	-0.0230	-0.0203	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/02/10

Material: Mix 20.0 **Technician:** SB

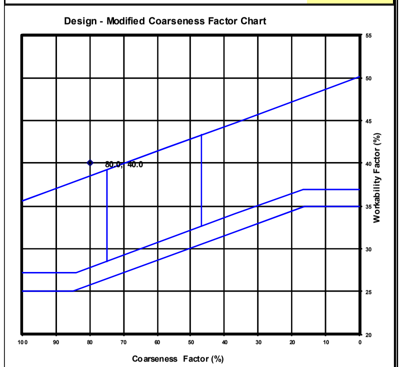
Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**75.87**	**77.81**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**119.180**	**123.070**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**121.130**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5170**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**22.8**	

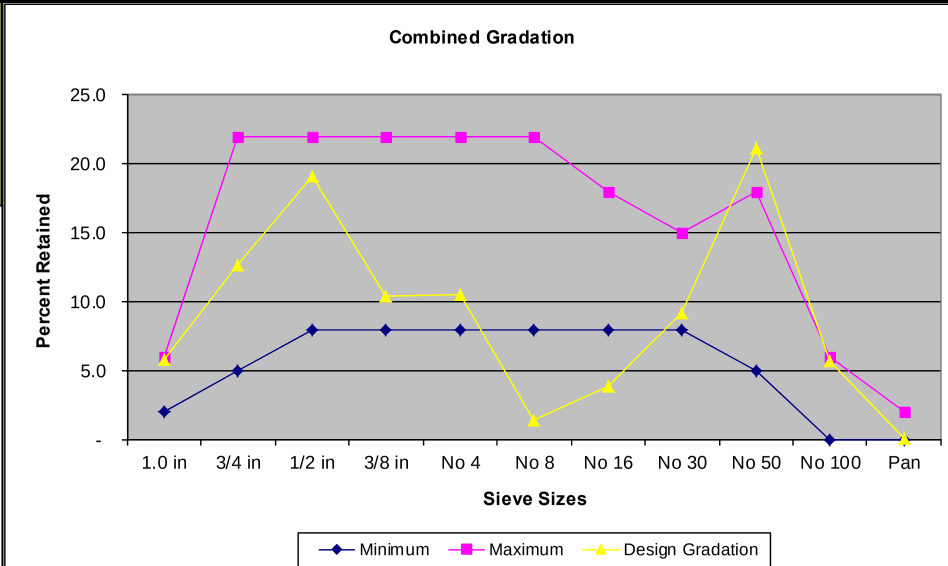
Reviewed By: Robert Varner, P.E. 8/2/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT			Project:	090594							MIX	21.0	
MIX NUMBER	MM16		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks								Set #:	MM16	
MIX	Date:	8/2/2010		f'c:	4,000 psi		Design w/c ratio		0.450		Size(c.f.):	1.25	Factor:	0.05
DESIGN INFO	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0020	13
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	5.7900	2.4770	2.200%	4.11	-	-2.200%	-0.18	1.1490	177.6530	8.2250	8.2250	8.27
3/4 in	5.0	22.0	12.7100	2.4770	2.200%	9.03	-	-2.200%	-0.40	2.5230	389.9770	18.0540	18.0540	18.05
1/2 in	8.0	22.0	19.0700	2.4770	2.200%	13.54	-	-2.200%	-0.60	3.7860	585.1180	27.0890	27.0890	27.09
3/8 in	8.0	22.0	10.4300	2.4770	2.200%	7.41	-	-2.200%	-0.33	2.0700	320.0200	14.8160	14.8160	14.82
No 4	8.0	22.0	10.5600	2.4880	2.200%	7.53	-	-2.200%	-0.33	2.0960	325.4480	15.0670	15.0670	15.7
No 8	8.0	22.0	1.4400	2.4880	2.200%	1.03	-	-2.200%	-0.05	0.2860	44.3790	2.0550	2.0550	2.06
No 16	8.0	18.0	3.8600	2.6280	0.260%	2.91	-	-0.260%	-0.02	0.7660	125.6550	5.8170	5.8170	5.82
No 30	8.0	15.0	9.2000	2.6280	0.260%	6.93	-	-0.260%	-0.04	1.8260	299.4890	13.8650	13.8650	13.87
No 50	5.0	18.0	21.1600	2.6280	0.260%	15.94	-	-0.260%	-0.08	4.2000	688.8240	31.8900	31.8900	31.89
No 100	-	6.0	5.7000	2.6280	0.260%	4.30	-	-0.260%	-0.02	1.1320	185.5530	8.5900	8.5900	8.59
Pan	-	2.0	0.0900	2.5370	1.420%	0.07	-	-1.420%	0.00	0.0180	2.8280	0.1310	0.1310	0.13
Total Grad%			100.0			72.80			-2.04	27.0010	3908.2240	180.9360	182.9710	183.6600

Fineness Mod			0.75
Q	23.0	72.0	48.0
I	16.0	44.0	12.0
W	21.0	59.0	40.0
CF Actual	52.4	69.6	80.0
WF Actual			40.0
AWF	24.4	47.6	39.01





Plastic Test Results

Batch Time	10:21 AM	% Air	3.50	Unit Wt w/o Air	148.45	Design w/c	0.450
Sample Time	10:30 AM	Bucket Weight	5.40	Unit Wt (pcf)	145.80	Actual w/c	0.450
Air Temp.	74.2	Bucket Full	41.85	Theorectial Air	1.79	Design Unit Wt	144.74
Mix Temp.	70.5	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.71
Slump, in.	3.00	Paste Volume (%)	23.79	Relative Yield	1.01	Bag Factor	5.60

Comments / Notes / Observations

Mix 21 - Manufactured Blend; 80/40

Pan Blend = 0.06, 0.02, 0.05

Mix Percent by Weight	
No. 57	48.00
No. 8	12.00
Sand	40.00
Combined Gravity Dry	2.5370
Combined Absorption	1.4200

Workability Measurements		
Workability Index	7.6	inches
Pre Vib Slump	2.75	inches
Post Vib.Slump	7.5	inches
Spread Length	13.375	inches
Spread Width	14.375	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/03/10	1	2310	2250
	1	2190	
08/09/10	7	4240	4325
	7	4410	
08/16/10	14	4800	4695
	14	4590	
08/30/10	28	5220	5417
	28	5490	
	28	5540	
09/27/10	56	5690	5650
	56	5610	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/2/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 21.0
Mix Date: Monday, August 02, 2010
Mix Time: 10:21 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8135	11.57680	1.6280	9.9488
2	10.0000	0.8150	0.8145	11.61135	1.6295	9.9819
3	10.0000	0.8150	0.8140	11.62080	1.6290	9.9918

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Tuesday, August 03, 2010	**0.0524**	**0.1003**	-0.0479	**0.0877**	**0.1003**	-0.0126	**0.0963**	**0.1003**	-0.0040	-0.0215	M/Rm

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Monday, August 30, 2010	**0.0529**	**0.1001**	0.0070	**0.0893**	**0.1001**	0.0180	**0.0968**	**0.1001**	0.0070	0.0107	Soak
32	Friday, September 03, 2010	**0.0522**	**0.1001**	0.0000	**0.0884**	**0.1001**	0.0090	**0.0960**	**0.1001**	-0.0010	0.0027	Shrinkage Room
35	Monday, September 06, 2010	**0.0518**	**0.1001**	-0.0040	**0.0879**	**0.1001**	0.0040	**0.0958**	**0.1001**	-0.0030	-0.0010	Shrinkage Room
42	Monday, September 13, 2010	**0.0514**	**0.0998**	-0.0050	**0.0873**	**0.0998**	0.0010	**0.0953**	**0.0998**	-0.0050	-0.0030	Shrinkage Room
56	Monday, September 27, 2010	**0.0505**	**0.0996**	-0.0120	**0.0863**	**0.0996**	-0.0070	**0.0946**	**0.0996**	-0.0100	-0.0097	Shrinkage Room
84	Monday, October 25, 2010	**0.0505**	**0.1008**	-0.0240	**0.0869**	**0.1008**	-0.0130	**0.0953**	**0.1008**	-0.0150	-0.0173	Shrinkage Room
140	Monday, December 20, 2010	**0.0499**	**0.1007**	-0.0290	**0.0862**	**0.1007**	-0.0190	**0.0943**	**0.1007**	-0.0240	-0.0240	Shrinkage Room
252	Monday, April 11, 2011	**0.0495**	**0.1003**	-0.0290	**0.0856**	**0.1003**	-0.0210	**0.0940**	**0.1003**	-0.0230	-0.0243	Shrinkage Room
476	Monday, November 21, 2011	**0.0499**	**0.1008**	-0.0300	**0.0859**	**0.1008**	-0.0230	**0.0943**	**0.1008**	-0.0250	-0.0260	Shrinkage Room

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/02/10

Material: Mix 21.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.98**	**79.48**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**125.410**	**126.410**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**125.910**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5370**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.3**	

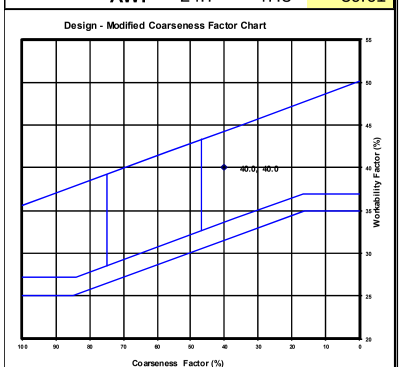
Reviewed By: Robert Varner, P.E. 8/2/2010

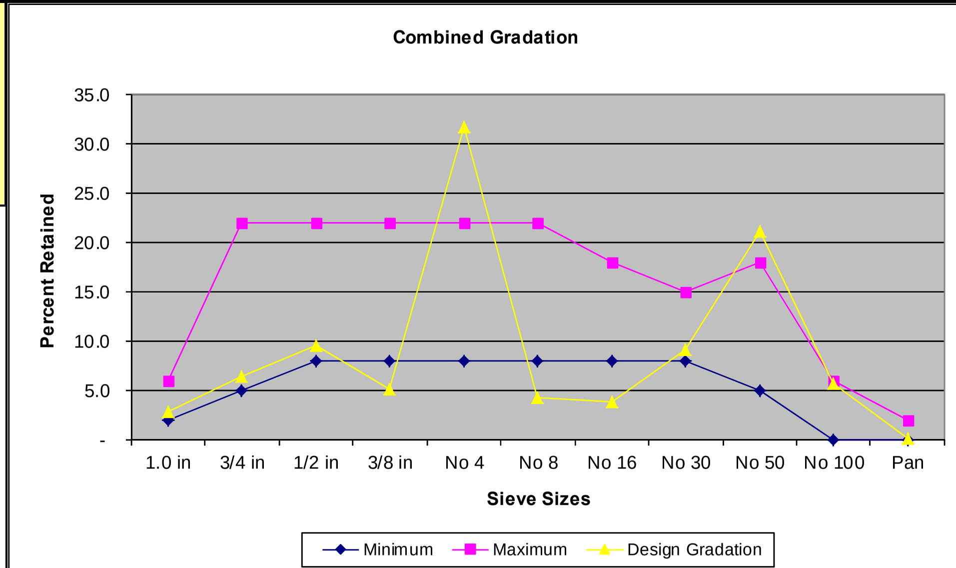
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594
MIX NUMBER	MM17	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks
MIX	22.0	Set #:	MM17
Date:	8/3/2010	f'c:	4,000 psi
Design w/c ratio	0.450	Size(c.f.):	1.25
Factor:	0.05		

MIX DESIGN INFO Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorption	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0050	13.00
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	2.8900	2.4770	2.200%	2.05	-	-2.200%	-0.09	0.5740	88.6730	4.1050	4.1050	4.10
3/4 in	5.0	22.0	6.3600	2.4770	2.200%	4.52	-	-2.200%	-0.20	1.2630	195.1420	9.0340	9.0340	9.03
1/2 in	8.0	22.0	9.5400	2.4770	2.200%	6.78	-	-2.200%	-0.30	1.8940	292.7130	13.5520	13.5520	13.55
3/8 in	8.0	22.0	5.2100	2.4770	2.200%	3.70	-	-2.200%	-0.16	1.0340	159.8570	7.4010	7.4010	7.4
No 4	8.0	22.0	31.6800	2.4880	2.200%	22.60	-	-2.200%	-0.99	6.2890	976.3430	45.2010	45.2010	45.20
No 8	8.0	22.0	4.3200	2.4880	2.200%	3.08	-	-2.200%	-0.14	0.8580	133.1380	6.1640	6.1640	6.16
No 16	8.0	18.0	3.8600	2.6280	0.260%	2.91	-	-0.260%	-0.02	0.7660	125.6550	5.8170	5.8170	5.82
No 30	8.0	15.0	9.2000	2.6280	0.260%	6.93	-	-0.260%	-0.04	1.8260	299.4890	13.8650	13.8650	13.87
No 50	5.0	18.0	21.1600	2.6280	0.260%	15.94	-	-0.260%	-0.08	4.2000	688.8240	31.8900	31.8900	31.89
No 100	-	6.0	5.7000	2.6280	0.260%	4.30	-	-0.260%	-0.02	1.1320	185.5530	8.5900	8.5900	8.59
Pan	-	2.0	0.0900	2.5390	1.420%	0.07	-	-1.420%	0.00	0.0180	2.8310	0.1310	0.1310	0.13
Total Grad%			100.0			72.88			-2.04	27.0030	3911.4980	181.0870	183.1250	183.1100

Fineness Mod			0.87
Q	23.0	72.0	24.0
I	16.0	44.0	36.0
W	21.0	59.0	40.0
CF Actual	52.4	69.6	40.0
WF Actual			40.0
AWF	24.7	47.3	39.01





Plastic Test Results

Batch Time	9:24 AM	% Air	4.00	Unit Wt w/o Air	148.57	Design w/c	0.450
Sample Time	9:33 AM	Bucket Weight	5.40	Unit Wt (pcf)	144.20	Actual w/c	0.450
Air Temp.	73.4	Bucket Full	41.45	Theorectial Air	2.94	Design Unit Wt	144.85
Mix Temp.	71	Bucket Volume	0.250	Yield	1.27	Fine/Coarse	0.71
Slump, in.	2.75	Paste Volume (%)	23.60	Relative Yield	1.02	Bag Factor	5.60

Comments / Notes / Observations

Mix 22 - Manufactured Blend; 40/40

Pan Blend = 0.03, 0.05, 0.05

Mix Percent by Weight	
No. 57	24.00
No. 8	36.00
Sand	40.00
Combined Gravity Dry	2.5390
Combined Absorption	1.4200

Workability Measurements

Workability Index	8.0	inches
Pre Vib Slump	2.25	inches
Post Vib.Slump	7.50	inches
Spread Length	14.25	inches
Spread Width	13.875	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/04/10	1	2330	2420
	1	2510	
08/10/10	7	3720	3665
	7	3610	
08/17/10	14	4070	4315
	14	4560	
08/31/10	28	5730	5110
	28	5280	
	28	4320	
09/28/10	56	4660	4830
	56	5000	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/3/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 22.0
Mix Date: Tuesday, August 03, 2010
Mix Time: 9:24 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8130	0.8135	11.61475	1.6265	9.9883
2	10.0000	0.8150	0.8125	11.60590	1.6275	9.9784
3	10.0000	0.8130	0.8155	11.63940	1.6285	10.0109

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Wednesday, August 04, 2010	**0.0896**	**0.1003**	-0.0107	**0.0813**	**0.1003**	-0.0190	**0.1153**	**0.1003**	0.0150	-0.0049	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Tuesday, August 31, 2010	**0.0908**	**0.1004**	0.0110	**0.0819**	**0.1004**	0.0050	**0.1143**	**0.1004**	Erratic	0.0080	**Soak**
32	Saturday, September 04, 2010	**0.0901**	**0.1004**	0.0040	**0.0811**	**0.1004**	-0.0030	**0.1135**	**0.1004**	Erratic	0.0005	**Shrinkage Room**
35	Tuesday, September 07, 2010	**0.0897**	**0.0999**	0.0050	**0.0806**	**0.0999**	-0.0030	**0.1132**	**0.0999**	Erratic	0.0010	
42	Tuesday, September 14, 2010	**0.0892**	**0.0999**	0.0000	**0.0801**	**0.0999**	-0.0080	**0.1126**	**0.0999**	Erratic	-0.0040	
56	Tuesday, September 28, 2010	**0.0883**	**0.0997**	-0.0070	**0.0792**	**0.0997**	-0.0150	**0.1118**	**0.0997**	Erratic	-0.0110	
84	Tuesday, October 26, 2010	**0.0885**	**0.1008**	-0.0160	**0.0795**	**0.1008**	-0.0230	**0.1119**	**0.1008**	Erratic	-0.0195	
140	Tuesday, December 21, 2010	**0.0879**	**0.1007**	-0.0210	**0.0786**	**0.1005**	-0.0290	**0.1110**	**0.1005**	Erratic	-0.0250	
252	Tuesday, April 12, 2011	**0.0871**	**0.1003**	-0.0250	**0.0781**	**0.1003**	-0.0320	**0.1106**	**0.1003**	Erratic	-0.0285	
476	Tuesday, November 22, 2011	**0.0874**	**0.1008**	-0.0270	**0.0783**	**0.1008**	-0.0350	**0.1109**	**0.1008**	Erratic	-0.0310	

Note: Specimen 3 has erratic data. However, continue to measure.

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/03/10

Material: Mix 22.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.03**	**77.61**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.510**	**122.670**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.090**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5390**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**22.2**	

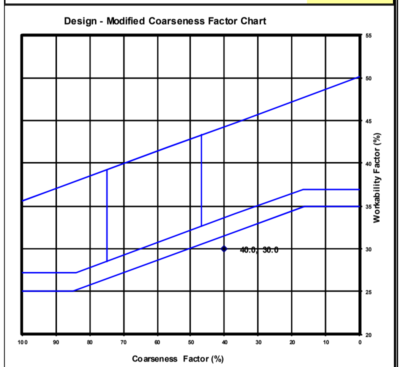
Reviewed By: Robert Varner, P.E. 8/3/2010

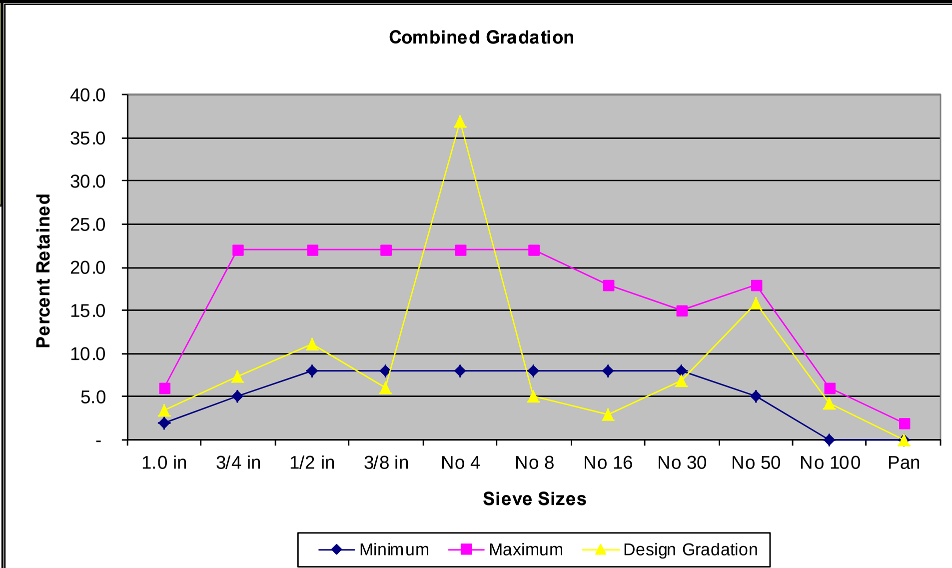
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594	MIX	23.0
MIX NUMBER	MM18	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	MM18

MIX DESIGN INFO	Date: 8/9/2010			f'c:	4,000 psi	Design w/c ratio		0.450		Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.6940	230.5350	10.6730	13.0060	13.01
Cementitious 1				3.15						2.6060	512.3000	23.7180	23.7180	23.72
1.0 in	2.0	6.0	3.3800	2.4770	2.200%	2.42	-	-2.200%	-0.11	0.6770	104.6160	4.8430	4.8430	4.87
3/4 in	5.0	22.0	7.4200	2.4770	2.200%	5.32	-	-2.200%	-0.23	1.4860	229.6610	10.6320	10.6320	10.64
1/2 in	8.0	22.0	11.1300	2.4770	2.200%	7.97	-	-2.200%	-0.35	2.2290	344.4910	15.9490	15.9490	15.96
3/8 in	8.0	22.0	6.0800	2.4770	2.200%	4.36	-	-2.200%	-0.19	1.2180	188.1860	8.7120	8.7120	8.71
No 4	8.0	22.0	36.9500	2.4880	2.200%	26.59	-	-2.200%	-1.17	7.3990	1148.7410	53.1820	53.1820	53.18
No 8	8.0	22.0	5.0500	2.4880	2.200%	3.63	-	-2.200%	-0.16	1.0110	157.0000	7.2690	7.2690	7.27
No 16	8.0	18.0	2.8900	2.6280	0.260%	2.20	-	-0.260%	-0.01	0.5790	94.9030	4.3940	4.3940	4.39
No 30	8.0	15.0	6.9000	2.6280	0.260%	5.25	-	-0.260%	-0.03	1.3820	226.5850	10.4900	10.4900	10.49
No 50	5.0	18.0	15.8700	2.6280	0.260%	12.06	-	-0.260%	-0.06	3.1780	521.1460	24.1270	24.1270	24.13
No 100	-	6.0	4.2700	2.6280	0.260%	3.25	-	-0.260%	-0.02	0.8550	140.2200	6.4920	6.4920	6.49
Pan	-	2.0	0.0700	2.5250	1.620%	0.05	-	-1.620%	0.00	0.0140	2.2090	0.1020	0.1020	0.1
Total Grad%			100.0			73.10			-2.33	27.0030	3900.5930	180.5830	182.9160	182.9600

Fineness Mod			0.85
Q	23.0	72.0	28.0
I	16.0	44.0	42.0
W	21.0	59.0	30.0
CF Actual	#NUM!	#NUM!	40.0
WF Actual			30.0
AWF	24.7	47.3	28.62





Plastic Test Results

Batch Time	3:06 PM	% Air	2.50	Unit Wt w/o Air	148.15	Design w/c	0.450
Sample Time	3:15 PM	Bucket Weight	5.40	Unit Wt (pcf)	146.20	Actual w/c	0.450
Air Temp.	77.2	Bucket Full	41.95	Theorectial Air	1.32	Design Unit Wt	144.45
Mix Temp.	75.5	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.45
Slump, in.	3.00	Paste Volume (%)	23.32	Relative Yield	1.00	Bag Factor	5.45

Comments / Notes / Observations

Mix 23 - Manufactured Blend; 40/30

Pan Blend = 0.03, 0.04, 0.03

Mix Percent by Weight	
No. 57	28.00
No. 8	42.00
Sand	30.00
Combined Gravity Dry	2.5250
Combined Absorption	1.6200

Workability Measurements		
Workability Index	7.3	inches
Pre Vib Slump	2.75	inches
Post Vib.Slump	6.5	inches
Spread Length	14.25	inches
Spread Width	14.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/10/10	1	2490	2365
	1	2240	
08/16/10	7	4390	4535
	7	4680	
08/23/10	14	4550	4510
	14	4470	
09/06/10	28	5800	5667
	28	5570	
	28	5630	
10/04/10	56	6760	6735
	56	6710	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/11/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 23.0
Mix Date Monday, August 09, 2010 Mix Time: 3:06 PM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8150	0.8120	11.63815	1.6270	10.0112
2	10.0000	0.8150	0.8130	11.61545	1.6280	9.9875
3	10.0000	0.8140	0.8145	11.64825	1.6285	10.0198

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Tuesday, August 10, 2010	**0.1141**	**0.1002**	0.0139	**0.0911**	**0.1002**	-0.0091	**0.1244**	**0.1002**	0.0242	0.0097	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Monday, September 06, 2010	**0.1137**	**0.1001**	-0.0030	**0.0912**	**0.1001**	0.0020	**0.1249**	**0.1001**	0.0060	0.0017	**Soak**
32	Friday, September 10, 2010	**0.1130**	**0.0998**	-0.0070	**0.0904**	**0.0998**	-0.0030	**0.1242**	**0.0998**	0.0020	-0.0027	**Shrinkage Room**
35	Monday, September 13, 2010	**0.1127**	**0.0998**	-0.0100	**0.0901**	**0.0998**	-0.0060	**0.1238**	**0.0998**	-0.0020	-0.0060	
42	Monday, September 20, 2010	**0.1119**	**0.0996**	-0.0160	**0.0894**	**0.0996**	-0.0110	**0.1231**	**0.0996**	-0.0070	-0.0113	
56	Monday, October 04, 2010	**0.1115**	**0.0998**	-0.0220	**0.0891**	**0.0998**	-0.0160	**0.1229**	**0.0998**	-0.0110	-0.0163	
84	Monday, November 01, 2010	**0.1116**	**0.1007**	-0.0300	**0.0890**	**0.1007**	-0.0260	**0.1228**	**0.1007**	-0.0210	-0.0257	
140	Monday, December 27, 2010	**0.1105**	**0.1003**	-0.0370	**0.0879**	**0.1003**	-0.0330	**0.1218**	**0.1003**	-0.0270	-0.0323	
252	Monday, April 18, 2011	**0.1099**	**0.0999**	-0.0390	**0.0873**	**0.0999**	-0.0350	**0.1213**	**0.0999**	-0.0280	-0.0340	
476	Monday, November 28, 2011	**0.1107**	**0.1008**	-0.0400	**0.0886**	**0.1008**	-0.0310	**0.1222**	**0.1008**	-0.0280	-0.0330	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/09/10

Material: Mix 23.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**77.93**	**78.34**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.310**	**124.130**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**123.720**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5250**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.4**	

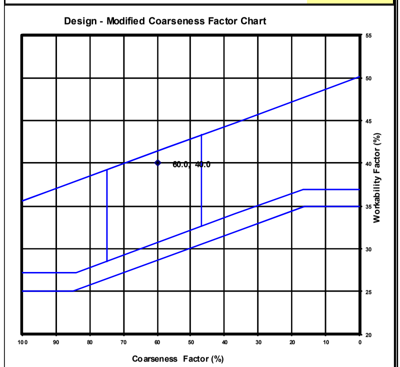
Reviewed By: Robert Varner, P.E. 8/11/2010

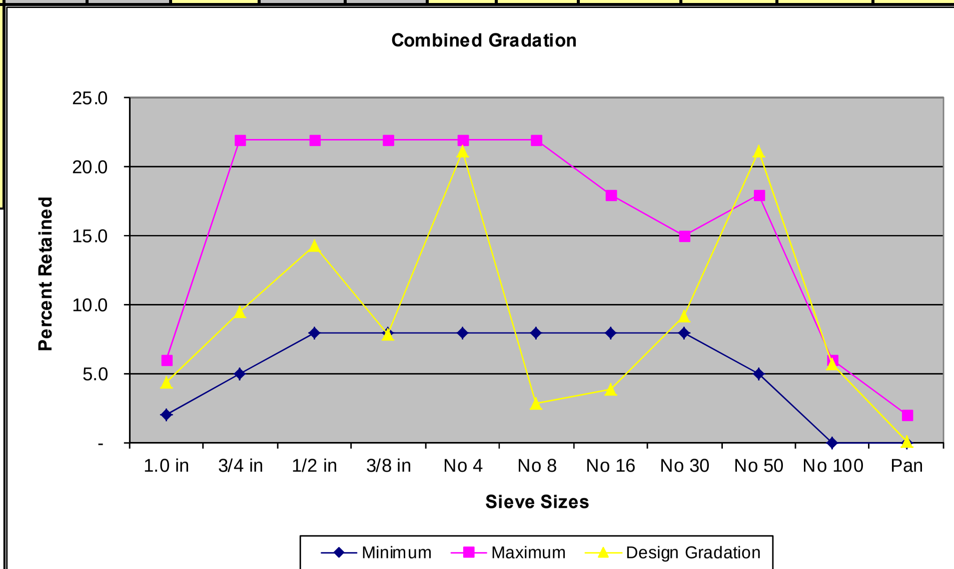
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594	MIX	24.0
MIX NUMBER	MM19	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	MM19

MIX DESIGN INFO	Date: 8/3/2010			f'c: 4,000 psi		Design w/c ratio	0.450			Size(c.f.):	1.25	Factor:	0.05	
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0040	13.00
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	4.3400	2.4770	2.200%	3.08	-	-2.200%	-0.14	0.8620	133.1630	6.1650	6.1650	6.18
3/4 in	5.0	22.0	9.5400	2.4770	2.200%	6.78	-	-2.200%	-0.30	1.8940	292.7130	13.5520	13.5520	13.55
1/2 in	8.0	22.0	14.3000	2.4770	2.200%	10.16	-	-2.200%	-0.45	2.8390	438.7620	20.3130	20.3130	20.32
3/8 in	8.0	22.0	7.8200	2.4770	2.200%	5.55	-	-2.200%	-0.24	1.5520	239.9380	11.1080	11.1080	11.11
No 4	8.0	22.0	21.1200	2.4880	2.200%	15.07	-	-2.200%	-0.66	4.1930	650.8950	30.1340	30.1340	30.13
No 8	8.0	22.0	2.8800	2.4880	2.200%	2.05	-	-2.200%	-0.09	0.5720	88.7580	4.1090	4.1090	4.11
No 16	8.0	18.0	3.8600	2.6280	0.260%	2.91	-	-0.260%	-0.02	0.7660	125.6550	5.8170	5.8170	5.82
No 30	8.0	15.0	9.2000	2.6280	0.260%	6.93	-	-0.260%	-0.04	1.8260	299.4890	13.8650	13.8650	13.87
No 50	5.0	18.0	21.1600	2.6280	0.260%	15.94	-	-0.260%	-0.08	4.2000	688.8240	31.8900	31.8900	31.89
No 100	-	6.0	5.7000	2.6280	0.260%	4.30	-	-0.260%	-0.02	1.1320	185.5530	8.5900	8.5900	8.59
Pan	-	2.0	0.0900	2.5380	1.420%	0.07	-	-1.420%	0.00	0.0180	2.8290	0.1310	0.1310	0.13
Total Grad%			100.0			72.84			-2.04	27.0030	3909.8590	181.0110	183.0480	183.0700

Fineness Mod			0.81
Q	23.0	72.0	36.0
I	16.0	44.0	24.0
W	21.0	59.0	40.0
CF Actual	52.4	69.6	60.0
WF Actual			40.0
AWF	23.0	49.0	39.01





Plastic Test Results

Batch Time	12:30 PM	% Air	4.00	Unit Wt w/o Air	148.51	Design w/c	0.450
Sample Time	12:39 PM	Bucket Weight	5.40	Unit Wt (pcf)	144.80	Actual w/c	0.450
Air Temp.	76.7	Bucket Full	41.6	Theorectial Air	2.50	Design Unit Wt	144.79
Mix Temp.	75.0	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.71
Slump, in.	2.50	Paste Volume (%)	23.70	Relative Yield	1.01	Bag Factor	5.60

Comments / Notes / Observations

Mix 24 - Manufactured Blend; 60/40

Pan Blend = 0.05, 0.03, 0.05

Mix Percent by Weight	
No. 57	36.00
No. 8	24.00
Sand	40.00
Combined Gravity Dry	2.5380
Combined Absorption	1.4200

Workability Measurements		
Workability Index	7.2	inches
Pre Vib Slump	1.75	inches
Post Vib.Slump	6.25	inches
Spread Length	13.00	inches
Spread Width	14.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/04/10	1	2400	2345
	1	2290	
08/10/10	7	4110	4090
	7	4070	
08/17/10	14	4190	4205
	14	4220	
08/31/10	28	4830	4810
	28	4560	
	28	5040	
09/28/10	56	5420	5695
	56	5970	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/4/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 24.0
Mix Date Tuesday, August 03, 2010 Mix Time: 12:30 PM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8125	0.8140	11.60950	1.6265	9.9830
2	10.0000	0.8140	0.8130	11.62515	1.6270	9.9982
3	10.0000	0.8150	0.8125	11.62465	1.6275	9.9972

SHRINKAGE TESTING - ASTM C157

INITIAL READINGS — Gage Length (in.): 10

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Wednesday, August 04, 2010	**0.0834**	**0.1003**	-0.0169	**0.1003**	**0.1003**	0.0000	**0.1004**	**0.1003**	0.0001	-0.0056	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Tuesday, August 31, 2010	**0.0845**	**0.1004**	0.0100	**0.1013**	**0.1004**	0.0090	**0.1013**	**0.1004**	0.0080	0.0090	**Soak**
32	Saturday, September 04, 2010	**0.0837**	**0.1003**	0.0030	**0.1004**	**0.1004**	0.0000	**0.1008**	**0.1004**	0.0030	0.0020	**Shrinkage Room**
35	Tuesday, September 07, 2010	**0.0831**	**0.0999**	0.0010	**0.0998**	**0.0999**	-0.0010	**0.1001**	**0.0999**	0.0010	0.0003	
42	Tuesday, September 14, 2010	**0.0826**	**0.0999**	-0.0040	**0.0993**	**0.0999**	-0.0060	**0.0994**	**0.0999**	-0.0060	-0.0053	
56	Tuesday, September 28, 2010	**0.0819**	**0.0997**	-0.0090	**0.0986**	**0.0997**	-0.0110	**0.0988**	**0.0997**	-0.0100	-0.0100	
84	Tuesday, October 26, 2010	**0.0821**	**0.1008**	-0.0180	**0.0991**	**0.1008**	-0.0170	**0.0989**	**0.1008**	-0.0200	-0.0183	
140	Tuesday, December 21, 2010	**0.0811**	**0.1005**	-0.0250	**0.0981**	**0.1005**	-0.0240	**0.0981**	**0.1005**	-0.0250	-0.0247	
252	Tuesday, April 12, 2011	**0.0807**	**0.1003**	-0.0270	**0.0979**	**0.1003**	-0.0240	**0.0975**	**0.1003**	-0.0290	-0.0267	
476	Tuesday, November 22, 2011	**0.0809**	**0.1008**	-0.0300	**0.0982**	**0.1008**	-0.0260	**0.0978**	**0.1008**	-0.0310	-0.0290	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/03/10

Material: Mix 24.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.74**	**79.33**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.930**	**126.110**

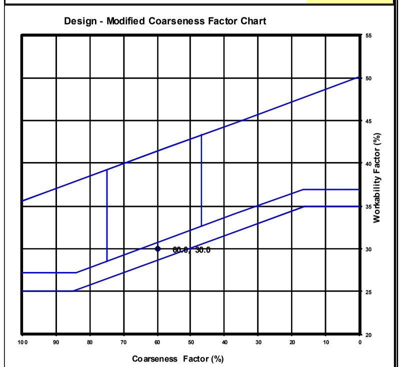
Void Content	
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**125.520**
Bulk Dry Specific Gravity of Aggregate, S	**2.5380**
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**
Void Content, % = 100[(S*W)-M]/(S*W)	**20.6**

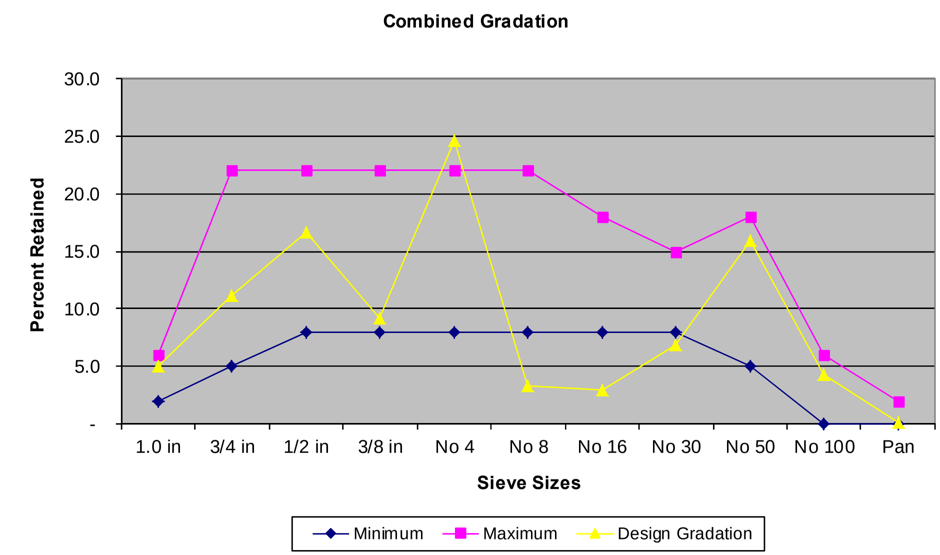
Reviewed By: Robert Varner, P.E. 8/4/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT			Project:	090594							MIX	25.0
MIX NUMBER	MM20		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks								Set #:	MM20
MIX	Date:	8/4/2010		f'c:	4,000 psi		Design w/c ratio	0.450		Size(c.f.):	1.25	Factor:	0.05
DESIGN INFO	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.4560	12.46
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	5.0600	2.4770	2.200%	3.69	-	-2.200%	-0.16	1.0310	159.3210	7.3760	7.3760	7.37
3/4 in	5.0	22.0	11.1300	2.4770	2.200%	8.11	-	-2.200%	-0.36	2.2670	350.4440	16.2240	16.2240	16.24
1/2 in	8.0	22.0	16.6900	2.4770	2.200%	12.16	-	-2.200%	-0.54	3.4000	525.5080	24.3290	24.3290	24.33
3/8 in	8.0	22.0	9.1300	2.4770	2.200%	6.65	-	-2.200%	-0.29	1.8600	287.4710	13.3090	13.3090	13.31
No 4	8.0	22.0	24.6400	2.4880	2.200%	18.04	-	-2.200%	-0.79	5.0190	779.2700	36.0770	36.0770	36.08
No 8	8.0	22.0	3.3600	2.4880	2.200%	2.46	-	-2.200%	-0.11	0.6840	106.2640	4.9200	4.9200	4.92
No 16	8.0	18.0	2.8900	2.6280	0.260%	2.23	-	-0.260%	-0.01	0.5890	96.5430	4.4700	4.4700	4.47
No 30	8.0	15.0	6.9000	2.6280	0.260%	5.34	-	-0.260%	-0.03	1.4060	230.5000	10.6710	10.6710	10.67
No 50	5.0	18.0	15.8700	2.6280	0.260%	12.27	-	-0.260%	-0.06	3.2330	530.1510	24.5440	24.5440	24.54
No 100	-	6.0	4.2700	2.6280	0.260%	3.30	-	-0.260%	-0.02	0.8700	142.6430	6.6040	6.6040	6.6
Pan	-	2.0	0.0700	2.5240	1.620%	0.05	-	-1.620%	0.00	0.0140	2.2460	0.1040	0.1040	0.1
Total Grad%			100.0			74.31			-2.37	27.0020	3912.3060	181.1250	183.4960	183.5000

Fineness Mod			0.78
Q	23.0	72.0	42.0
I	16.0	44.0	28.0
W	21.0	59.0	30.0
CF Actual	#NUM!	#NUM!	60.0
WF Actual			30.0
AWF	23.0	49.0	27.87





Plastic Test Results

Batch Time	10:06 AM	% Air	2.25	Unit Wt w/o Air	148.60	Design w/c	0.450
Sample Time	10:15 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.40	Actual w/c	0.450
Air Temp.	76.5	Bucket Full	42.00	Theorectial Air	1.48	Design Unit Wt	144.89
Mix Temp.	73	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.45
Slump, in.	2.50	Paste Volume (%)	22.00	Relative Yield	1.00	Bag Factor	5.15

Comments / Notes / Observations

Mix 25 - Manufactured Blend; 60/30

Pan Blend = 0.04, 0.03, 0.03

Mix Percent by Weight	
No. 57	42.00
No. 8	28.00
Sand	30.00
Combined Gravity Dry	2.5240
Combined Absorption	1.6200

Workability Measurements		
Workability Index	4.7	inches
Pre Vib Slump	1.75	inches
Post Vib.Slump	4.50	inches
Spread Length	12.00	inches
Spread Width	11.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/05/10	1	2730	2705
	1	2680	
08/11/10	7	4160	4200
	7	4240	
08/18/10	14	4580	4455
	14	4330	
09/01/10	28	5060	5203
	28	5130	
	28	5420	
09/29/10	56	6000	5940
	56	5880	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/4/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 25.0
Mix Date Wednesday, August 04, 2010 Mix Time: 10:06 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8190	0.8175	11.62020	1.6365	9.9837
2	10.0000	0.8145	0.8130	11.62740	1.6275	9.9999
3	10.0000	0.8155	0.8170	11.62250	1.6325	9.9900

SHRINKAGE TESTING - ASTM C157

	Gage Length (in.)	INITIAL READINGS										
	10	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
Specimen Age	Test date	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Thursday, August 05, 2010	**0.1031**	**0.1003**	0.0028	**0.0967**	**0.1003**	-0.0036	**0.0981**	**0.1003**	-0.0022	-0.0010	M/Rm
		LENGTH CHANGE CALCULATIONS										
		Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Wednesday, September 01, 2010	**0.1037**	**0.1002**	0.0070	**0.0971**	**0.1002**	0.0050	**0.0985**	**0.1002**	0.0050	0.0057	Soak
32	Sunday, September 05, 2010	**0.1029**	**0.1002**	-0.0010	**0.0962**	**0.1002**	-0.0040	**0.0976**	**0.1002**	-0.0040	-0.0030	Shrinkage Room
35	Wednesday, September 08, 2010	**0.1027**	**0.1001**	-0.0020	**0.0960**	**0.1001**	-0.0050	**0.0974**	**0.1000**	-0.0040	-0.0037	
42	Wednesday, September 15, 2010	**0.1021**	**0.0999**	-0.0060	**0.0954**	**0.0999**	-0.0090	**0.0968**	**0.0999**	-0.0090	-0.0080	
56	Wednesday, September 29, 2010	**0.1014**	**0.0997**	-0.0110	**0.0948**	**0.0997**	-0.0130	**0.0962**	**0.0997**	-0.0130	-0.0123	
84	Wednesday, October 27, 2010	**0.1016**	**0.1008**	-0.0200	**0.0951**	**0.1008**	-0.0210	**0.0964**	**0.1008**	-0.0220	-0.0210	
140	Wednesday, December 22, 2010	**0.1005**	**0.1003**	-0.0260	**0.0939**	**0.1003**	-0.0280	**0.0952**	**0.1003**	-0.0290	-0.0277	
252	Wednesday, April 13, 2011	**0.1005**	**0.1003**	-0.0260	**0.0938**	**0.1003**	-0.0290	**0.0950**	**0.1003**	-0.0310	-0.0287	
476	Wednesday, November 23, 2011	**0.1007**	**0.1008**	-0.0290	**0.0942**	**0.1008**	-0.0300	**0.0954**	**0.1008**	-0.0320	-0.0303	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/04/10

Material: Mix 25.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**77.85**	**77.06**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**123.150**	**121.560**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**122.360**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5240**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**22.2**	

Reviewed By: Robert Varner, P.E. 8/4/2010

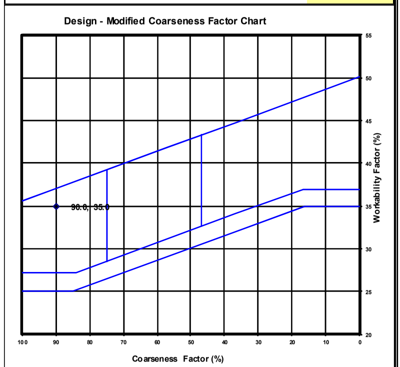
Burns Cooley Dennis, Inc - State Study No. 231

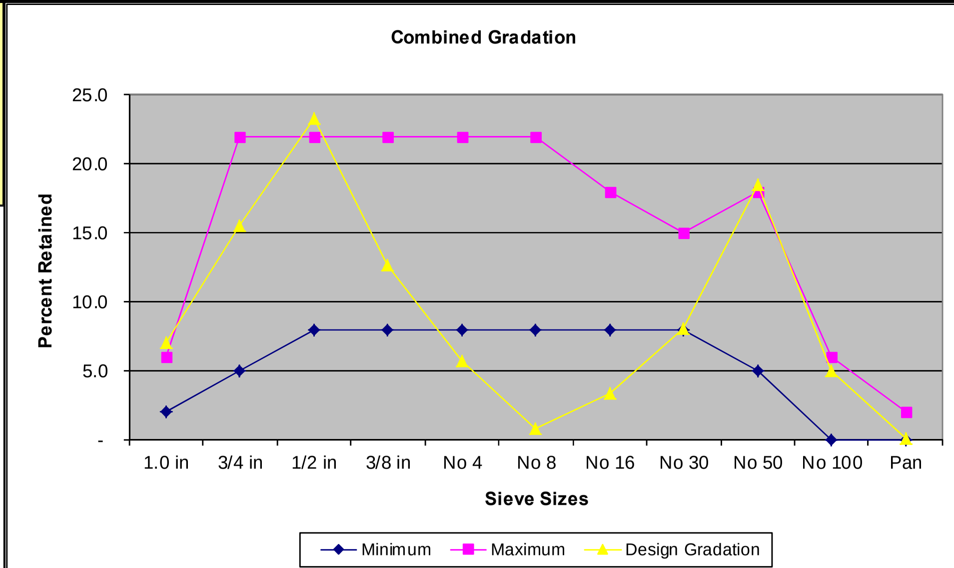
Customer: **MDOT** | Project: **090594** | MIX **26.0**

MIX NUMBER MM21 | Notes: Optimizing MS Aggregates for Concrete Bridge Decks | Set #: MM21

MIX DESIGN INFO	Date: 8/4/2010			f'c: 4,000 psi		Design w/c ratio	0.450		Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.3130	12.31
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	7.0500	2.4770	2.200%	5.14	-	-2.200%	-0.23	1.4360	221.9790	10.2770	10.2770	10.28
3/4 in	5.0	22.0	15.5000	2.4770	2.200%	11.30	-	-2.200%	-0.50	3.1580	488.0390	22.5940	22.5940	22.60
1/2 in	8.0	22.0	23.2400	2.4770	2.200%	16.94	-	-2.200%	-0.75	4.7340	731.7440	33.8770	33.8770	33.88
3/8 in	8.0	22.0	12.7100	2.4770	2.200%	9.26	-	-2.200%	-0.41	2.5890	400.1920	18.5270	18.5270	18.53
No 4	8.0	22.0	5.7200	2.4880	2.200%	4.19	-	-2.200%	-0.18	1.1650	180.9020	8.3750	8.3750	8.38
No 8	8.0	22.0	0.7800	2.4880	2.200%	0.57	-	-2.200%	-0.03	0.1590	24.6680	1.1420	1.1420	1.14
No 16	8.0	18.0	3.3700	2.6280	0.260%	2.61	-	-0.260%	-0.01	0.6870	112.5780	5.2120	5.2120	5.21
No 30	8.0	15.0	8.0500	2.6280	0.260%	6.22	-	-0.260%	-0.03	1.6400	268.9170	12.4500	12.4500	12.45
No 50	5.0	18.0	18.5200	2.6280	0.260%	14.32	-	-0.260%	-0.07	3.7730	618.6760	28.6420	28.6420	28.64
No 100	-	6.0	4.9800	2.6280	0.260%	3.85	-	-0.260%	-0.02	1.0140	166.3610	7.7020	7.7020	7.70
Pan	-	2.0	0.0800	2.5290	1.520%	0.06	-	-1.520%	0.00	0.0160	2.5720	0.1190	0.1190	0.12
Total Grad%			100.0			74.46			-2.23	27.0000	3918.5730	181.4140	183.6420	183.6500

Fineness Mod			0.70
Q	23.0	72.0	58.5
I	16.0	44.0	6.5
W	21.0	59.0	35.0
CF Actual	52.9	69.1	90.0
WF Actual			35.0
AWF	26.5	45.5	32.88





Plastic Test Results

Batch Time	10:40 AM	% Air	3.00	Unit Wt w/o Air	148.85	Design w/c	0.450
Sample Time	10:49 AM	Bucket Weight	5.40	Unit Wt (pcf)	145.80	Actual w/c	0.450
Air Temp.	76.9	Bucket Full	41.85	Theorectial Air	2.05	Design Unit Wt	145.13
Mix Temp.	73	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.57
Slump, in.	2.75	Paste Volume (%)	21.88	Relative Yield	1.01	Bag Factor	5.15

Comments / Notes / Observations

Mix 26 - Manufactured Blend; 90/35

Pan Blend = 0.07, 0.01, 0.04

Mix Percent by Weight	
No. 57	58.50
No. 8	6.50
Sand	35.00
Combined Gravity Dry	2.5290
Combined Absorption	1.5200

Workability Measurements		
Workability Index	6.2	inches
Pre Vib Slump	2.00	inches
Post Vib.Slump	5.50	inches
Spread Length	13.00	inches
Spread Width	13.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/05/10	1	2500	2380
	1	2260	
08/11/10	7	3800	3960
	7	4120	
08/18/10	14	4480	4535
	14	4590	
09/01/10	28	4810	4630
	28	4290	
	28	4790	
09/29/10	56	5800	5650
	56	5500	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/4/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 26.0
Mix Date: Wednesday, August 04, 2010 Mix Time: 10:40 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8140	0.8150	11.62215	1.6290	9.9932
2	10.0000	0.8140	0.8130	11.62255	1.6270	9.9956
3	10.0000	0.8140	0.8165	11.64665	1.6305	10.0162

SHRINKAGE TESTING - ASTM C157

INITIAL READINGS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
	Gage Length (in.): 10	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Thursday, August 05, 2010	**0.0992**	**0.1003**	-0.0011	**0.0980**	**0.1003**	-0.0023	**0.1219**	**0.1003**	0.0216	0.0061	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Wednesday, September 01, 2010	**0.0997**	**0.1002**	0.0060	**0.0985**	**0.1002**	0.0060	**0.1225**	**0.1002**	0.0070	0.0063	**Soak**
32	Sunday, September 05, 2010	**0.0989**	**0.1002**	-0.0020	**0.0975**	**0.1001**	-0.0030	**0.1217**	**0.1001**	0.0000	-0.0017	**Shrinkage Room**
35	Wednesday, September 08, 2010	**0.0986**	**0.1000**	-0.0030	**0.0974**	**0.1001**	-0.0040	**0.1213**	**0.1001**	-0.0040	-0.0037	
42	Wednesday, September 15, 2010	**0.0981**	**0.0999**	-0.0070	**0.0970**	**0.0999**	-0.0060	**0.1208**	**0.0999**	-0.0070	-0.0067	
56	Wednesday, September 29, 2010	**0.0974**	**0.0997**	-0.0120	**0.0964**	**0.0997**	-0.0100	**0.1201**	**0.0997**	-0.0120	-0.0113	
84	Wednesday, October 27, 2010	**0.0979**	**0.1008**	-0.0180	**0.0966**	**0.1008**	-0.0190	**0.1205**	**0.1008**	-0.0190	-0.0187	
140	Wednesday, December 22, 2010	**0.0968**	**0.1002**	-0.0230	**0.0956**	**0.1002**	-0.0230	**0.1194**	**0.1002**	-0.0240	-0.0233	
252	Wednesday, April 13, 2011	**0.0965**	**0.1003**	-0.0270	**0.0955**	**0.1003**	-0.0250	**0.1192**	**0.1003**	-0.0270	-0.0263	
476	Wednesday, November 23, 2011	**0.0970**	**0.1008**	-0.0270	**0.0958**	**0.1008**	-0.0270	**0.1196**	**0.1008**	-0.0280	-0.0273	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/04/10

Material: Mix 26.0 **Technician:** SB

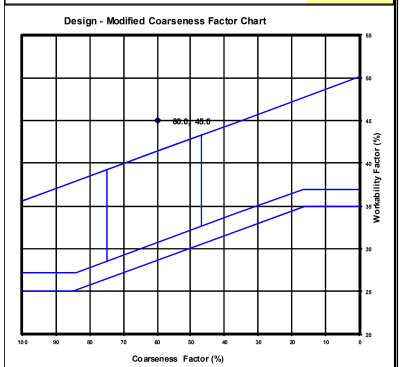
Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**79.61**	**79.32**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**126.670**	**126.090**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**126.380**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5290**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**19.8**	

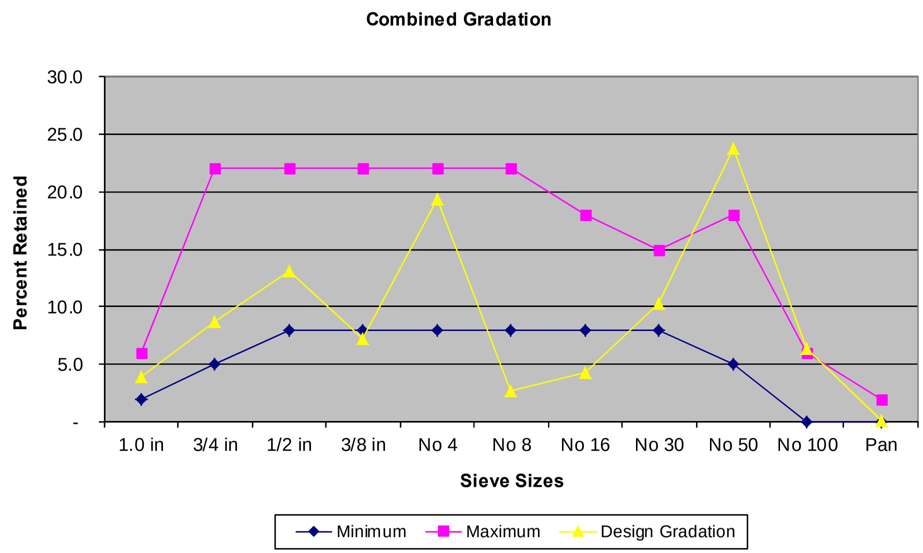
Reviewed By: Robert Varner, P.E. 8/4/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT			Project:	090594								MIX	27.0
MIX NUMBER	MM22		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks									Set #:	MM22
MIX DESIGN INFO	Date:	8/5/2010		f'c:	4,000 psi		Design w/c ratio		0.450		Size(c.f.):	1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						4.1690	260.1450	12.0440	13.8810	13.88
Cementitious 1				3.15						2.9410	578.1000	26.7640	26.7640	26.76
1.0 in	2.0	6.0	3.9800	2.4770	2.200%	2.74	-	-2.200%	-0.12	0.7650	118.2050	5.4720	5.4720	5.47
3/4 in	5.0	22.0	8.7400	2.4770	2.200%	6.01	-	-2.200%	-0.26	1.6790	259.5750	12.0170	12.0170	12.02
1/2 in	8.0	22.0	13.1100	2.4770	2.200%	9.01	-	-2.200%	-0.40	2.5190	389.3620	18.0260	18.0260	18.03
3/8 in	8.0	22.0	7.1700	2.4770	2.200%	4.93	-	-2.200%	-0.22	1.3780	212.9460	9.8590	9.8590	9.86
No 4	8.0	22.0	19.3600	2.4880	2.200%	13.37	-	-2.200%	-0.59	3.7200	577.5380	26.7380	26.7380	26.74
No 8	8.0	22.0	2.6400	2.4880	2.200%	1.82	-	-2.200%	-0.08	0.5070	78.7550	3.6460	3.6460	3.65
No 16	8.0	18.0	4.3400	2.6280	0.260%	3.17	-	-0.260%	-0.02	0.8340	136.7540	6.3310	6.3310	6.33
No 30	8.0	15.0	10.3500	2.6280	0.260%	7.55	-	-0.260%	-0.04	1.9890	326.1300	15.0990	15.0990	15.1
No 50	5.0	18.0	23.8100	2.6280	0.260%	17.37	-	-0.260%	-0.09	4.5750	750.2560	34.7340	34.7340	34.73
No 100	-	6.0	6.4100	2.6280	0.260%	4.68	-	-0.260%	-0.02	1.2320	201.9800	9.3510	9.3510	9.35
Pan	-	2.0	0.1000	2.5450	0.260%	0.07	-	-0.260%	0.00	0.0190	3.0510	0.1410	0.1410	0.14
Total Grad%			100.0			70.71			-1.84	27.0020	3892.7970	180.2220	182.0590	182.0600

Fineness Mod			0.83
Q	23.0	72.0	33.0
I	16.0	44.0	22.0
W	21.0	59.0	45.0
CF Actual	#NUM!	#NUM!	60.0
WF Actual			45.0
AWF	23.0	49.0	45.38





Plastic Test Results

Batch Time	10:47 AM	% Air	3.50	Unit Wt w/o Air	147.86	Design w/c	0.450
Sample Time	10:56 AM	Bucket Weight	5.40	Unit Wt (pcf)	144.20	Actual w/c	0.450
Air Temp.	77.2	Bucket Full	41.45	Theorectial Air	2.48	Design Unit Wt	144.17
Mix Temp.	75.5	Bucket Volume	0.250	Yield	1.26	Fine/Coarse	0.87
Slump, in.	3.00	Paste Volume (%)	26.07	Relative Yield	1.01	Bag Factor	6.15

Comments / Notes / Observations

Mix 27 - Manufactured Blend; 60/45

Pan Blend = 0.05, 0.03, 0.06

Mix Percent by Weight	
No. 57	33.00
No. 8	22.00
Sand	45.00
Combined Gravity Dry	2.5450
Combined Absorption	1.3300

Workability Measurements		
Workability Index	8.5	inches
Pre Vib Slump	2.0	inches
Post Vib.Slump	7.5	inches
Spread Length	14.50	inches
Spread Width	14.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/06/10	1	2550	2615
	1	2680	
08/12/10	7	4140	4020
	7	3900	
08/19/10	14	5060	4830
	14	4600	
09/02/10	28	4570	4490
	28	4520	
	28	4380	
09/30/10	56	5750	5660
	56	5570	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/11/2010

BURNS COOLEY DENNIS, INC.

GEOTECHNICAL & MATERIALS CONSULTANTS

State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 27.0

Mix Date Thursday, August 05, 2010 Mix Time: 10:47 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8145	0.8140	11.61970	1.6285	9.9912
2	10.0000	0.8130	0.8120	11.62950	1.6250	10.0045
3	10.0000	0.8140	0.8150	11.61295	1.6290	9.9840

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	(.0001 in.)	(.0001 in.)	Inches	Inches	
1	Friday, August 06, 2010	**0.0915**	**0.1003**	-0.0088	**0.1052**	**0.1003**	0.0049	**0.0888**	**0.1003**	-0.0115	-0.0051	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1	Reference Bar 1	Δ Length 1	Specimen 2	Reference Bar 2	Δ Length 2	Specimen 3	Reference Bar 3	Δ Length 3	Average	
		(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001 in.)	(.0001 in.)	(0.0001%)	(.0001%)	
28	Thursday, September 02, 2010	**0.0917**	**0.1002**	0.0030	**0.1050**	**0.1002**	-0.0010	**0.0887**	**0.1002**	0.0000	0.0007	**Soak**
32	Monday, September 06, 2010	**0.0905**	**0.1001**	-0.0080	**0.1038**	**0.1001**	-0.0120	**0.0874**	**0.1001**	-0.0120	-0.0107	**Shrinkage Room**
35	Thursday, September 09, 2010	**0.0901**	**0.0997**	-0.0080	**0.1037**	**0.0997**	-0.0090	**0.0870**	**0.0997**	-0.0120	-0.0097	
42	Thursday, September 16, 2010	**0.0897**	**0.0997**	-0.0120	**0.1031**	**0.0997**	-0.0150	**0.0868**	**0.0997**	-0.0140	-0.0137	
56	Thursday, September 30, 2010	**0.0890**	**0.0998**	-0.0200	**0.1025**	**0.0998**	-0.0220	**0.0860**	**0.0998**	-0.0230	-0.0217	
84	Thursday, October 28, 2010	**0.0888**	**0.1008**	-0.0320	**0.1024**	**0.1008**	-0.0330	**0.0861**	**0.1008**	-0.0320	-0.0323	
140	Thursday, December 23, 2010	**0.0878**	**0.1002**	-0.0360	**0.1013**	**0.1002**	-0.0380	**0.0848**	**0.1002**	-0.0390	-0.0377	
252	Thursday, April 14, 2011	**0.0875**	**0.1003**	-0.0400	**0.1010**	**0.1003**	-0.0420	**0.0846**	**0.1003**	-0.0420	-0.0413	
476	Thursday, November 24, 2011	**0.0878**	**0.1008**	-0.0420	**0.1011**	**0.1008**	-0.0460	**0.0853**	**0.1008**	-0.0400	-0.0427	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/05/10

Material: Mix 27.0 **Technician:** SB

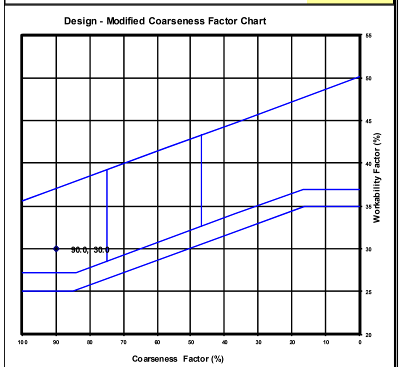
Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.84**	**78.65**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**125.130**	**124.750**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.940**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5450**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.2**	

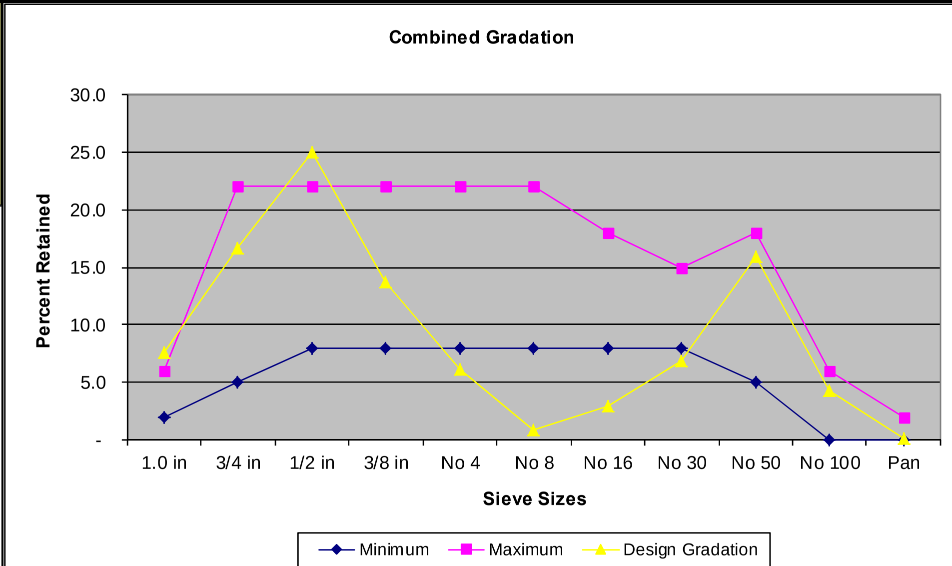
Reviewed By: Robert Varner, P.E. 8/11/2010

Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT			Project:	090594								MIX	28.0
MIX NUMBER	MM23		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks									Set #:	MM23
MIX	Date:	8/9/2010		f'c:	4,000 psi		Design w/c ratio	0.450		Size(c.f.):	1.25		Factor:	0.05
DESIGN INFO	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.4910	217.8450	10.0850	12.4530	12.45
Cementitious 1				3.15						2.4630	484.1000	22.4120	22.4120	22.41
1.0 in	2.0	6.0	7.5900	2.4770	2.200%	5.53	-	-2.200%	-0.24	1.5460	238.9820	11.0640	11.0640	11.06
3/4 in	5.0	22.0	16.6900	2.4770	2.200%	12.16	-	-2.200%	-0.54	3.4000	525.5080	24.3290	24.3290	24.34
1/2 in	8.0	22.0	25.0300	2.4770	2.200%	18.24	-	-2.200%	-0.80	5.0990	788.1040	36.4860	36.4860	36.49
3/8 in	8.0	22.0	13.6900	2.4770	2.200%	9.98	-	-2.200%	-0.44	2.7890	431.0490	19.9560	19.9560	19.96
No 4	8.0	22.0	6.1600	2.4880	2.200%	4.51	-	-2.200%	-0.20	1.2550	194.8180	9.0190	9.0190	9.02
No 8	8.0	22.0	0.8400	2.4880	2.200%	0.61	-	-2.200%	-0.03	0.1710	26.5660	1.2300	1.2300	1.23
No 16	8.0	18.0	2.8900	2.6280	0.260%	2.23	-	-0.260%	-0.01	0.5890	96.5430	4.4700	4.4700	4.47
No 30	8.0	15.0	6.9000	2.6280	0.260%	5.34	-	-0.260%	-0.03	1.4060	230.5000	10.6710	10.6710	10.67
No 50	5.0	18.0	15.8700	2.6280	0.260%	12.27	-	-0.260%	-0.06	3.2330	530.1510	24.5440	24.5440	24.54
No 100	-	6.0	4.2700	2.6280	0.260%	3.30	-	-0.260%	-0.02	0.8700	142.6430	6.6040	6.6040	6.6
Pan	-	2.0	0.0700	2.5210	1.620%	0.05	-	-1.620%	0.00	0.0140	2.2430	0.1040	0.1040	0.1
Total Grad%			100.0			74.24			-2.37	27.0010	3909.0520	180.9740	183.3420	183.3400

Fineness Mod			0.67
Q	23.0	72.0	63.0
I	16.0	44.0	7.0
W	21.0	59.0	30.0
CF Actual	#NUM!	#NUM!	90.0
WF Actual			30.0
AWF	26.5	45.5	27.88





Plastic Test Results

Batch Time	3:43 PM	% Air	2.25	Unit Wt w/o Air	148.49	Design w/c	0.450
Sample Time	3:52 PM	Bucket Weight	5.40	Unit Wt (pcf)	147.60	Actual w/c	0.450
Air Temp.	77.0	Bucket Full	42.3	Theorectial Air	0.60	Design Unit Wt	144.77
Mix Temp.	74	Bucket Volume	0.250	Yield	1.24	Fine/Coarse	0.45
Slump, in.	3.25	Paste Volume (%)	22.19	Relative Yield	0.99	Bag Factor	5.15

Comments / Notes / Observations

Mix 28 - Manufactured Blend; 90/30

Pan Blend = 0.7, 0.01, 0.3

Mix Percent by Weight	
No. 57	63.00
No. 8	7.00
Sand	30.00
Combined Gravity Dry	2.5210
Combined Absorption	1.6200

Workability Measurements		
Workability Index	5.2	inches
Pre Vib Slump	4.0	inches
Post Vib.Slump	7.0	inches
Spread Length	12.25	inches
Spread Width	12.25	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/10/10	1	2380	2280
	1	2180	
08/16/10	7	4410	4515
	7	4620	
08/23/10	14	5370	4695
	14	4020	
09/06/10	28	5790	5917
	28	5850	
	28	6110	
10/04/10	56	6560	6655
	56	6750	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/11/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number Mix 28.0
Mix Date Monday, August 09, 2010 Mix Time: 3:43 PM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8150	0.8145	11.63970	1.6295	10.0102
2	10.0000	0.8135	0.8140	11.62190	1.6275	9.9944
3	10.0000	0.8145	0.8140	11.63650	1.6285	10.0080

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Tuesday, August 10, 2010	**0.1154**	**0.1000**	0.0154	**0.0981**	**0.0999**	-0.0018	**0.1119**	**0.0999**	0.0120	0.0085	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Monday, September 06, 2010	**0.1155**	**0.1000**	0.0010	**0.0984**	**0.1000**	0.0020	**0.1121**	**0.1000**	0.0010	0.0013	**Soak**
32	Friday, September 10, 2010	**0.1148**	**0.0998**	-0.0040	**0.0979**	**0.0998**	-0.0010	**0.1115**	**0.0998**	-0.0030	-0.0027	**Shrinkage Room**
35	Monday, September 13, 2010	**0.1145**	**0.0998**	-0.0070	**0.0976**	**0.0998**	-0.0040	**0.1112**	**0.0998**	-0.0060	-0.0057	
42	Monday, September 20, 2010	**0.1139**	**0.0996**	-0.0110	**0.0970**	**0.0996**	-0.0080	**0.1106**	**0.0996**	-0.0100	-0.0097	
56	Monday, October 04, 2010	**0.1137**	**0.0998**	-0.0150	**0.0966**	**0.0998**	-0.0140	**0.1104**	**0.0998**	-0.0140	-0.0143	
84	Monday, November 01, 2010	**0.1146**	**0.1012**	-0.0200	**0.0973**	**0.1012**	-0.0210	**0.1110**	**0.1012**	-0.0220	-0.0210	
140	Monday, December 27, 2010	**0.1128**	**0.1003**	-0.0290	**0.0959**	**0.1003**	-0.0260	**0.1096**	**0.1003**	-0.0270	-0.0273	
252	Monday, April 18, 2011	**0.1126**	**0.0999**	-0.0270	**0.0958**	**0.0999**	-0.0230	**0.1092**	**0.0999**	-0.0270	-0.0257	
476	Monday, November 28, 2011	**0.1133**	**0.1008**	-0.0290	**0.0964**	**0.1008**	-0.0260	**0.1102**	**0.1008**	-0.0260	-0.0270	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/09/10

Material: Mix 28.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.69**	**79.51**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.830**	**126.470**

Void Content	
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**125.650**
Bulk Dry Specific Gravity of Aggregate, S	**2.5210**
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**
Void Content, % = 100[(S*W)-M]/(S*W)	**20.0**

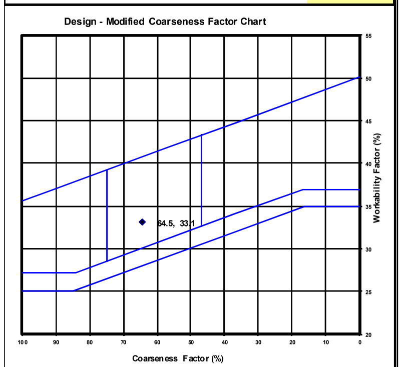
Reviewed By: Robert Varner, P.E. 8/11/2010

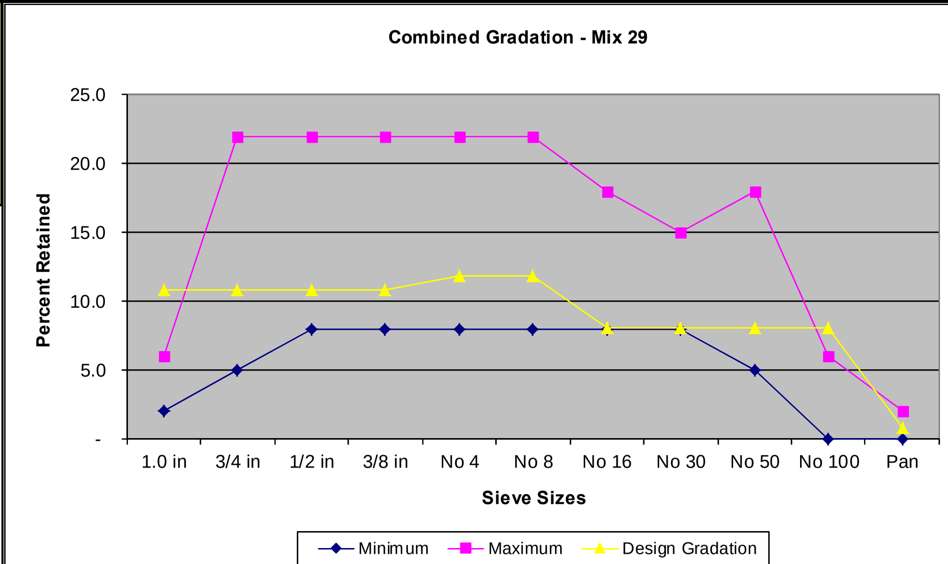
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT			Project:	090594							MIX	29.0
MIX NUMBER	MM24		Notes:	Optimizing MS Aggregates for Concrete Bridge Decks								Set #:	MM24
MIX DESIGN INFO	Date:	8/11/2010		f'c:	4,000 psi		Design w/c ratio		0.450	Size(c.f.):	1.25	Factor:	0.05

Material	% Retained MDOT Min	Max	Design	DRY Specific Gravity	AGG Absorp-tion	AGG Dry U.W 0.625	AGG Moisture Content	Free H20 Content	Batch Free H2O	Volume (c.f.)	DRY Mix 1 cu yd Wt. (lbs.)	DRY Mix lab batch Wt. (lbs.)	Adjusted lab batch Wt. (lbs.)	Actual lab batch Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.2020	13.2
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	10.7900	2.4770	2.200%	7.66	-	-2.200%	-0.34	2.1420	331.0660	15.3270	15.3270	15.32
3/4 in	5.0	22.0	10.7900	2.4770	2.200%	7.66	-	-2.200%	-0.34	2.1420	331.0660	15.3270	15.3270	15.33
1/2 in	8.0	22.0	10.7900	2.4770	2.200%	7.66	-	-2.200%	-0.34	2.1420	331.0660	15.3270	15.3270	15.33
3/8 in	8.0	22.0	10.7900	2.4770	2.200%	7.66	-	-2.200%	-0.34	2.1420	331.0660	15.3270	15.3270	15.33
No 4	8.0	22.0	11.8700	2.4770	2.200%	8.43	-	-2.200%	-0.37	2.3560	364.2030	16.8610	16.8610	16.86
No 8	8.0	22.0	11.8700	2.4770	2.200%	8.43	-	-2.200%	-0.37	2.3560	364.2030	16.8610	16.8610	16.86
No 16	8.0	18.0	8.0700	2.6280	0.260%	6.08	-	-0.260%	-0.03	1.6020	262.7040	12.1620	12.1620	12.16
No 30	8.0	15.0	8.0700	2.6280	0.260%	6.08	-	-0.260%	-0.03	1.6020	262.7040	12.1620	12.1620	12.16
No 50	5.0	18.0	8.0700	2.6280	0.260%	6.08	-	-0.260%	-0.03	1.6020	262.7040	12.1620	12.1620	12.16
No 100	-	6.0	8.0700	2.6280	0.260%	6.08	-	-0.260%	-0.03	1.6020	262.7040	12.1620	12.1620	12.16
Pan	-	2.0	0.8100	2.5250	1.560%	0.59	-	-1.560%	-0.02	0.1610	25.3350	1.1730	1.1730	1.2
Total Grad%			100.0			72.43			-2.24	26.9980	3892.1010	180.1880	182.4230	182.4400

Fineness Mod			0.78
Q	23.0	72.0	43.2
I	16.0	44.0	23.7
W	21.0	59.0	33.1
CF Actual	58.2	63.8	64.5
WF Actual			33.1
AWF	23.0	49.0	32.09





Plastic Test Results

Batch Time	9:29 AM	% Air	2.50	Unit Wt w/o Air	147.86	Design w/c	0.450
Sample Time	9:38 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.40	Actual w/c	0.450
Air Temp.	72.0	Bucket Full	42	Theorectial Air	0.99	Design Unit Wt	144.16
Mix Temp.	70	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.52
Slump, in.	4.5	Paste Volume (%)	24.05	Relative Yield	1.00	Bag Factor	5.60

Comments / Notes / Observations

Mix 29 - Repeat of Mix 1 with different gradation curve

Slump measured 3 times, 5.0, 6.25, 4.0, respectively. Second slump test was not valid, (shear).

No 57 was used for the No. 4 and No 8 to better replicate Mix 1

Pan Blend = 0.8, 0.0, 0.4

Mix Percent by Weight

No. 57	66.90
No. 8	0.00
Sand	33.10
Combined Gravity Dry	2.5250
Combined Absorption	1.5600

Workability Measurements

Workability Index	8.8	inches
Pre Vib Slump	4.0	inches
Post Vib.Slump	8.75	inches
Spread Length	15.25	inches
Spread Width	15.50	inches

Strength Test Results

Date	AGE (4x8 CYLINDERS)	psi	Avg. psi
08/12/10	1	2750	2765
	1	2780	
08/18/10	7	4430	4645
	7	4860	
08/25/10	14	5220	5335
	14	5450	
09/08/10	28	5150	5330
	28	5500	
	28	5340	
10/06/10	56	5590	5720
	56	5850	

Technician who conducted tests:

Reviewed by: Robert Varner, P.E. 8/11/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 29.0
Mix Date: Wednesday, August 11, 2010 Mix Time: 9:29 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8155	0.8150	11.64080	1.6305	10.0103
2	10.0000	0.8135	0.8145	11.61205	1.6280	9.9841
3	10.0000	0.8160	0.8125	11.68170	1.6285	10.0532

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Thursday, August 12, 2010	**0.1156**	**0.1002**	0.0154	**0.0861**	**0.1002**	-0.0141	**0.1652**	**0.1002**	0.0650	0.0221	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Wednesday, September 08, 2010	**0.1181**	**0.0999**	Erratic	**0.0865**	**0.0999**	0.0070	**0.1652**	**0.0999**	0.0030	0.0050	**Soak**
32	Sunday, September 12, 2010	**0.1173**	**0.1001**	Erratic	**0.0858**	**0.1001**	-0.0020	**0.1644**	**0.1001**	-0.0070	-0.0045	**Shrinkage Room**
35	Wednesday, September 15, 2010	**0.1169**	**0.0999**	Erratic	**0.0854**	**0.0999**	-0.0040	**0.1641**	**0.0999**	-0.0080	-0.0060	
42	Wednesday, September 22, 2010	**0.1164**	**0.0998**	Erratic	**0.0849**	**0.0998**	-0.0080	**0.1636**	**0.0998**	-0.0120	-0.0100	
56	Wednesday, October 06, 2010	**0.1157**	**0.0997**	Erratic	**0.0843**	**0.0997**	-0.0130	**0.1629**	**0.0997**	-0.0180	-0.0155	
84	Wednesday, November 03, 2010	**0.1157**	**0.1009**	Erratic	**0.0843**	**0.1009**	-0.0250	**0.1630**	**0.1009**	-0.0290	-0.0270	
140	Wednesday, December 29, 2010	**0.1148**	**0.1002**	Erratic	**0.0834**	**0.1003**	-0.0280	**0.1622**	**0.1002**	-0.0300	-0.0290	
252	Wednesday, April 20, 2011	**0.1140**	**0.1000**	Erratic	**0.0826**	**0.1000**	-0.0330	**0.1615**	**0.1000**	-0.0350	-0.0340	
476	Wednesday, November 30, 2011	**0.1146**	**0.1007**	Erratic	**0.0832**	**0.1007**	-0.0340	**0.1622**	**0.1007**	-0.0350	-0.0345	

Note: Specimen 1 has erratic data. However, continue to measure

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/11/10

Material: Mix 29.0 **Technician:** SB

Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.71**	**79.26**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.870**	**125.970**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**125.420**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5250**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**20.3**	

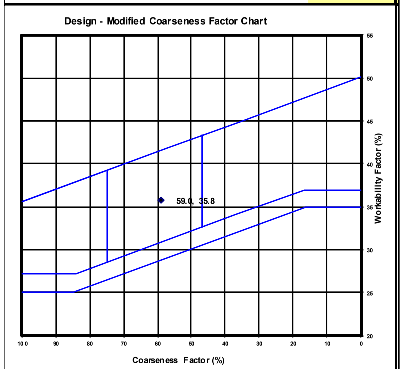
Reviewed By: Robert Varner 8/11/2010

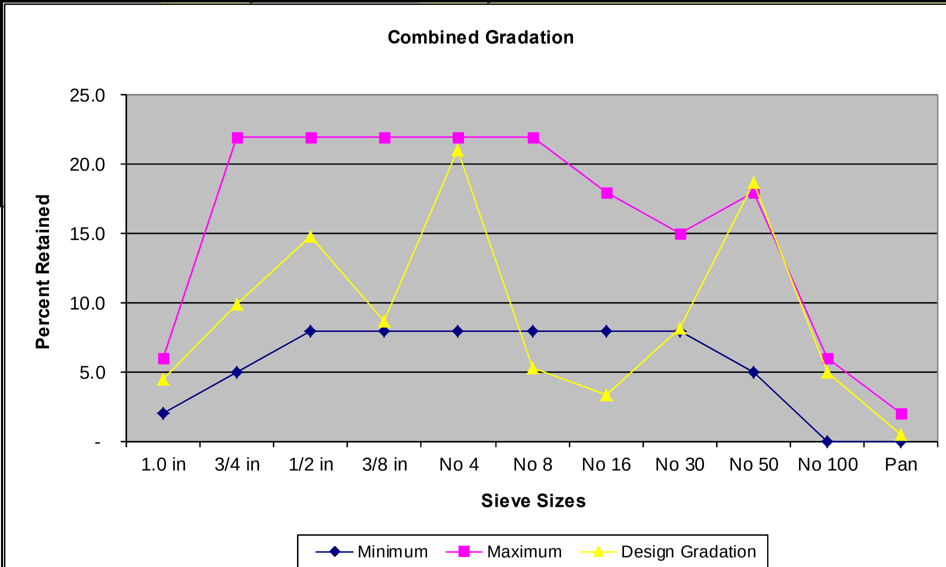
Burns Cooley Dennis, Inc - State Study No. 231

Customer:	MDOT	Project:	090594	MIX	30.0
MIX NUMBER	GC205	Notes:	Optimizing MS Aggregates for Concrete Bridge Decks	Set #:	GC205

MIX DESIGN INFO	Date: 8/11/2010			f'c:	4,000 psi		Design w/c ratio		0.450	Size(c.f.):		1.25	Factor:	0.05
	% Retained MDOT			DRY Specific	AGG Absorp-	AGG Dry U.W	AGG Moisture	Free H20	Batch Free	Volume	DRY Mix 1 cu yd	DRY Mix lab batch	Adjusted lab batch	Actual lab batch
Material	Min	Max	Design	Gravity	tion	0.625	Content	Content	H2O	(c.f.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)	Wt. (lbs.)
Entrapped Air			2.50%							0.6750				
Water				1.000						3.7960	236.8800	10.9670	13.0740	13.644
Cementitious 1				3.15						2.6780	526.4000	24.3700	24.3700	24.37
1.0 in	2.0	6.0	4.5000	2.5340	1.450%	3.27	-	-1.450%	-0.09	0.8930	141.2490	6.5390	6.5390	6.55
3/4 in	5.0	22.0	9.9000	2.5340	1.450%	7.19	-	-1.450%	-0.21	1.9650	310.7480	14.3860	14.3860	14.40
1/2 in	8.0	22.0	14.8500	2.5340	1.450%	10.79	-	-1.450%	-0.31	2.9480	466.1220	21.5800	21.5800	21.59
3/8 in	8.0	22.0	8.6300	2.5340	1.450%	6.27	-	-1.450%	-0.18	1.7130	270.8850	12.5410	12.5410	12.54
No 4	8.0	22.0	21.0200	2.5340	1.450%	15.27	-	-1.450%	-0.44	4.1730	659.7910	30.5460	30.5460	30.54
No 8	8.0	22.0	5.3100	2.5340	1.450%	3.86	-	-1.450%	-0.11	1.0540	166.6740	7.7160	7.7160	7.72
No 16	8.0	18.0	3.4100	2.5340	1.450%	2.48	-	-1.450%	-0.07	0.6770	107.0360	4.9550	4.9550	4.96
No 30	8.0	15.0	8.1300	2.5340	1.450%	5.91	-	-1.450%	-0.17	1.6140	255.1900	11.8140	11.8140	11.81
No 50	5.0	18.0	18.6900	2.5340	1.450%	13.58	-	-1.450%	-0.39	3.7100	586.6550	27.1600	27.1600	27.16
No 100	-	6.0	5.0300	2.5340	1.450%	3.65	-	-1.450%	-0.11	0.9990	157.8850	7.3090	7.3090	7.31
Pan	-	2.0	0.5300	2.5340	1.450%	0.39	-	-1.450%	-0.01	0.1050	16.6360	0.7700	0.7700	0.8
Total Grad%			100.0			72.66			-2.11	27.0000	3902.1510	180.6530	182.7600	183.3940

Fineness Mod			0.80
Q	23.0	72.0	37.9
I	16.0	44.0	26.3
W	21.0	59.0	35.8
CF Actual	48.6	73.4	59.0
WF Actual			35.8
AWF	23.0	49.0	34.79





Comments / Notes / Observations

Mix 30 - KU Optimized Blend +1.5gal water/yd³

Batched as a blend

Mix Percent by Weight	
No. 57	55.60
No. 8	5.70
Sand	38.70
Combined Gravity Dry	2.5340
Combined Absorption	1.4500

Workability Measurements		
Workability Index	8.3	inches
Pre Vib Slump	4.25	inches
Post Vib.Slump	7.75	inches
Spread Length	15.50	inches
Spread Width	15.50	inches

Strength Test Results

Date	AGE	psi	Avg. psi
	4x8 CYLINDERS		
08/12/10	1	2330	2400
	1	2470	
08/18/10	7	4250	4305
	7	4360	
08/25/10	14	4620	4645
	14	4670	
09/08/10	28	4620	4677
	28	4810	
	28	4600	
10/06/10	56	5780	5760
	56	5740	

Technician who conducted tests:

Plastic Test Results

Batch Time	10:14 AM	% Air	2.75	Unit Wt w/o Air	148.23	Design w/c	0.450
Sample Time	10:23 AM	Bucket Weight	5.40	Unit Wt (pcf)	146.40	Actual w/c	0.473
Air Temp.	72.7	Bucket Full	42	Theorectial Air	1.23	Design Unit Wt	144.52
Mix Temp.	70	Bucket Volume	0.250	Yield	1.25	Fine/Coarse	0.56
Slump, in.	5.5	Paste Volume (%)	24.66	Relative Yield	1.00	Bag Factor	5.60

Reviewed by: Robert Varner, P.E. 8/11/2010

BURNS COOLEY DENNIS, INC.
GEOTECHNICAL & MATERIALS CONSULTANTS
State Study 231 - ASTM C 157 Shrinkage Testing

278 COMMERCE PARK DRIVE
RIDGELAND, MS 39157

BUS: (601) 856-2332
FAX: (601) 856-3552

BCD JOB NO. 090594

Mix Number: Mix 30.0
Mix Date: Wednesday, August 11, 2010
Mix Time: 10:14 AM

Measurements Required Before Making Specimens

Specimen	Length of Standard Bar Distance Betw. Studs (0.0001 in.)	Length Stud 1 (0.0001 inches)	Length Stud 2 (0.0001 inches)	Measured Length of Specimen	Combined Stud Length	Net Distance betw Studs
1	10.0000	0.8125	0.8145	11.58705	1.6270	9.9601
2	10.0000	0.8140	0.8150	11.62530	1.6290	9.9963
3	10.0000	0.8145	0.8130	11.65940	1.6275	10.0319

SHRINKAGE TESTING - ASTM C157

Gage Length (in.): 10

INITIAL READINGS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 Inches	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 Inches	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 Inches	Average Inches	
1	Thursday, August 12, 2010	**0.0620**	**0.1002**	-0.0382	**0.1002**	**0.1002**	0.0000	**0.1342**	**0.1002**	0.0340	-0.0014	**M/Rm**

LENGTH CHANGE CALCULATIONS

Specimen Age	Test date	Specimen 1 (.0001 in.)	Reference Bar 1 (.0001 in.)	Δ Length 1 (0.0001%)	Specimen 2 (.0001 in.)	Reference Bar 2 (.0001 in.)	Δ Length 2 (0.0001%)	Specimen 3 (.0001 in.)	Reference Bar 3 (.0001 in.)	Δ Length 3 (0.0001%)	Average (.0001%)	
28	Wednesday, September 08, 2010	**0.0622**	**0.0999**	0.0050	**0.1002**	**0.0999**	0.0030	**0.1342**	**0.0999**	0.0030	0.0037	**Soak**
32	Sunday, September 12, 2010	**0.0613**	**0.1001**	-0.0060	**0.0994**	**0.1001**	-0.0070	**0.1334**	**0.1001**	-0.0070	-0.0067	**Shrinkage Room**
35	Wednesday, September 15, 2010	**0.0612**	**0.0999**	-0.0050	**0.0991**	**0.0999**	-0.0080	**0.1330**	**0.0999**	-0.0090	-0.0073	
42	Wednesday, September 22, 2010	**0.0606**	**0.0998**	-0.0100	**0.0986**	**0.0998**	-0.0120	**0.1325**	**0.0998**	-0.0130	-0.0117	
56	Wednesday, October 06, 2010	**0.0602**	**0.0997**	-0.0130	**0.0980**	**0.0997**	-0.0170	**0.1320**	**0.0997**	-0.0170	-0.0157	
84	Wednesday, November 03, 2010	**0.0603**	**0.1009**	-0.0240	**0.0981**	**0.1009**	-0.0280	**0.1321**	**0.1009**	-0.0280	-0.0267	
140	Wednesday, December 29, 2010	**0.0593**	**0.1002**	-0.0270	**0.0974**	**0.1002**	-0.0280	**0.1311**	**0.1002**	-0.0310	-0.0287	
252	Wednesday, April 20, 2011	**0.0587**	**0.1000**	-0.0310	**0.0968**	**0.1000**	-0.0320	**0.1305**	**0.1000**	-0.0350	-0.0327	
476	Wednesday, November 30, 2011	**0.0593**	**0.1007**	-0.0320	**0.0974**	**0.1007**	-0.0330	**0.1312**	**0.1007**	-0.0350	-0.0333	

Note: Lowest Reading Value Recorded. Reviewed By: Robert Varner, P.E. Date: 8/9/2012

BURNS COOLEY DENNIS, INC.

State Study No. 231

Optimizing MS Aggregates for Concrete Bridge Decks

Determining Unit Weight and Voids in Aggregate (AASHTO T 19)

Project: 090594 **Date:** 08/11/10

Material: Mix 30.0 **Technician:** SB

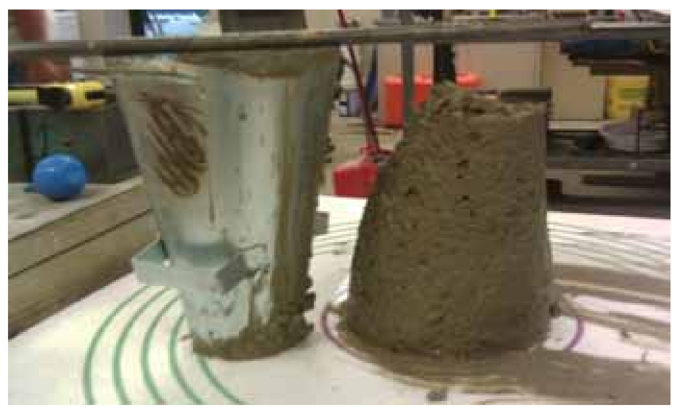
Unit Weight		
Sample Number:	1	2
Calibrated volume of measure, V, ft^3 (m^3)	**0.499**	**0.499**
Tare weight of measure, T, lb (kg)	**16.40**	**16.40**
Mass of aggregate plus measure, G, lb (kg)	**78.49**	**78.81**
Unit weight of aggregate, M, lb/ft^3 (kg/m^3) M=(G-T)/V	**124.430**	**125.070**
Void Content		
Average unit weight, M_{avg}, lb/ft^3 (kg/m^3)	**124.750**	
Bulk Dry Specific Gravity of Aggregate, S	**2.5340**	
Density of Water, (62.3 lb/ft^3) (998 kg/m^3)	**62.3**	
Void Content, % = 100[(S*W)-M]/(S*W)	**21.0**	

Reviewed By: Robert Varner, P.E. 8/11/10

Appendix C

Photographs of Mixes:

Mix 1.0



Plastic Properties

Slump, in.	3.25
% Air	2.75
Paste Volume	24.01
Unit Wt (pcf)	146.2
Actual w/c	0.45
W/(Q+I)	0.50
Cement Content	526.4

Pre-Vib Slump	3.75
Post-Vib Slump	6.25
Spread Length	14.5
Spread Width	13.5
WI	6.5
CF	64.5
WF	33.1
AWF	32.1

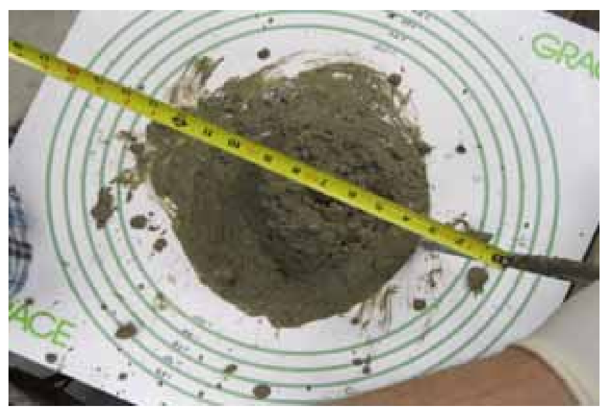
Mix 2.0

Plastic Properties

Slump, in.	3.25
% Air	3
Paste Volume	23.82
Unit Wt (pcf)	145.2
Actual w/c	0.45
W/(Q+I)	0.59
Cement Content	526.4

Pre-Vib Slump	3.75
Post-Vib Slump	6.25
Spread Length	14.5
Spread Width	13.5
WI	6.5
CF	61.0
WF	36.0
AWF	35.0

Mix 3.0



Plastic Properties

Slump, in.	3.25	Pre-Vib Slump	2.25
% Air	3	Post-Vib Slump	4.75
Paste Volume	23.87	Spread Length	14
Unit Wt (pcf)	145.6	Spread Width	10.75
Actual w/c	0.45	WI	5.0
W/(Q+I)	0.56	CF	59.0
Cement Content	526.4	WF	35.8
		AWF	34.8

Mix 4.0

Plastic Properties

Slump, in.	3.5
% Air	3.25
Paste Volume	23.71
Unit Wt (pcf)	144.6
Actual w/c	0.45
W/(Q+I)	0.59
Cement Content	526.4

Pre-Vib Slump	2.0
Post-Vib Slump	5.0
Spread Length	13
Spread Width	12.75
WI	5.7
CF	58.9
WF	35.7
AWF	34.7

Mix 5.0

Plastic Properties

Slump, in.	3	Pre-Vib Slump	4.0
% Air	1.75	Post-Vib Slump	5.75
Paste Volume	24.15	Spread Length	12
Unit Wt (pcf)	146.8	Spread Width	12.25
Actual w/c	0.45	WI	4.5
W/(Q+I)	0.31	CF	39.2
Cement Content	526.4	WF	23.5
		AWF	22.5

Mix 6.0

Plastic Properties

Slump, in.	3
% Air	5.75
Paste Volume	25.94
Unit Wt (pcf)	143.6
Actual w/c	0.45
W/(Q+I)	0.85
Cement Content	578.1

Pre-Vib Slump	2.75
Post-Vib Slump	6.5
Spread Length	15.25
Spread Width	15
WI	8.1
CF	40.7
WF	46.1
AWF	46.5

Mix 7.0

Plastic Properties

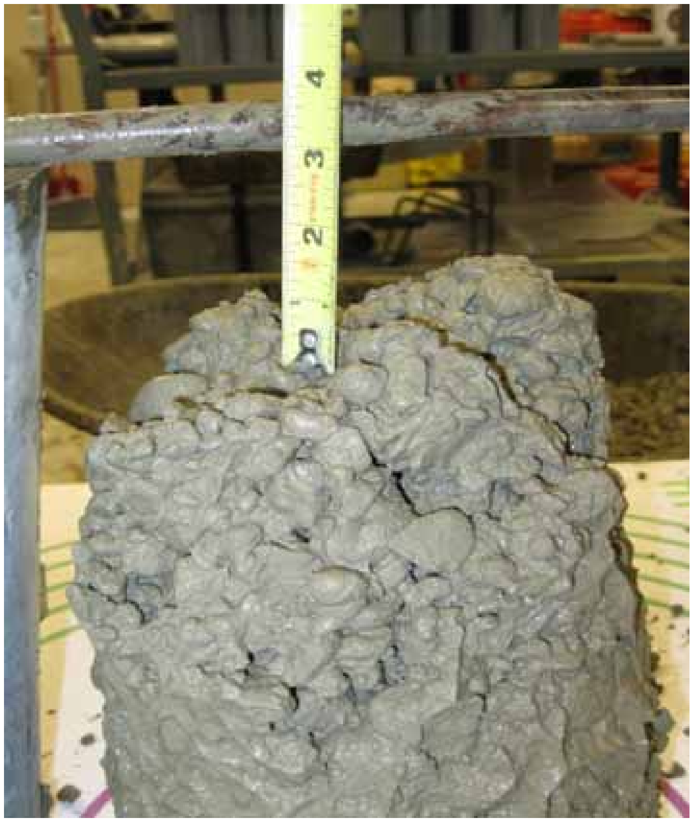
Slump, in.	2.5	Pre-Vib Slump	2.25
% Air	2	Post-Vib Slump	4.5
Paste Volume	22.22	Spread Length	11
Unit Wt (pcf)	147.8	Spread Width	11
Actual w/c	0.45	WI	3.8
W/(Q+I)	0.45	CF	80.0
Cement Content	484.1	WF	30.0
		AWF	27.9

Mix 8.0

Plastic Properties

Slump, in.	2.75	Pre-Vib Slump	2.25
% Air	3.25	Post-Vib Slump	4.75
Paste Volume	26.31	Spread Length	12.25
Unit Wt (pcf)	145.4	Spread Width	10.5
Actual w/c	0.45	WI	4.2
W/(Q+I)	0.90	CF	80.0
Cement Content	578.1	WF	46.1
		AWF	46.5

Mix 9.0



Plastic Properties

Slump, in.	3.5	Pre-Vib Slump	3.0
% Air	1.5	Post-Vib Slump	6.5
Paste Volume	24.28	Spread Length	13
Unit Wt (pcf)	147.2	Spread Width	13.25
Actual w/c	0.452	WI	6.2
W/(Q+I)	0.31	CF	58.2
Cement Content	526.4	WF	23.4
		AWF	22.4

Mix 10.0

Plastic Properties

Slump, in.	3.25
% Air	3.75
Paste Volume	25.46
Unit Wt (pcf)	144.4
Actual w/c	0.45
W/(Q+I)	0.71
Cement Content	564

Pre-Vib Slump	3.25
Post-Vib Slump	8.75
Spread Length	17
Spread Width	15
WI	9.7
CF	58.2
WF	41.5
AWF	41.5

Mix 11.0

Plastic Properties

Slump, in.	2.75	Pre-Vib Slump	2.25
% Air	2.5	Post-Vib Slump	5.5
Paste Volume	22.01	Spread Length	12.5
Unit Wt (pcf)	146.6	Spread Width	12.25
Actual w/c	0.45	WI	5.5
W/(Q+I)	0.57	CF	85.0
Cement Content	484.1	WF	35.0
		AWF	32.9

Mix 12.0

Plastic Properties

Slump, in.	2.5
% Air	3
Paste Volume	23.88
Unit Wt (pcf)	145.8
Actual w/c	0.45
W/(Q+I)	0.59
Cement Content	526.4

Pre-Vib Slump	1.75
Post-Vib Slump	5.5
Spread Length	13.25
Spread Width	13
WI	6.4
CF	36.3
WF	37.1
AWF	36.1

Mix 13.0

Plastic Properties

Slump, in.	2.5	Pre-Vib Slump	2.0
% Air	3.25	Post-Vib Slump	5.5
Paste Volume	22.02	Spread Length	12.5
Unit Wt (pcf)	146.8	Spread Width	13
Actual w/c	0.45	WI	5.9
W/(Q+I)	0.57	CF	72.5
Cement Content	484.1	WF	35.0
		AWF	32.9

Mix 14.0

Plastic Properties

Slump, in.	2.5	Pre-Vib Slump	2.0
% Air	4.25	Post-Vib Slump	5.0
Paste Volume	23.69	Spread Length	10.75
Unit Wt (pcf)	144.68	Spread Width	10.125
Actual w/c	0.45	WI	3.9
W/(Q+I)	0.71	CF	70.0
Cement Content	526.4	WF	40.0
		AWF	39.0

Mix 15.0

Plastic Properties

Slump, in.	2.75
% Air	4
Paste Volume	23.58
Unit Wt (pcf)	144.08
Actual w/c	0.45
W/(Q+I)	0.71
Cement Content	526.4

Pre-Vib Slump	2.50
Post-Vib Slump	8.25
Spread Length	14.875
Spread Width	13.625
WI	8.5
CF	50.0
WF	40.0
AWF	39.0

Mix 16.0

Plastic Properties

Slump, in.	3.25	Pre-Vib Slump	2.0
% Air	2.5	Post-Vib Slump	5.0
Paste Volume	22.06	Spread Length	12.5
Unit Wt (pcf)	146.8	Spread Width	12
Actual w/c	0.45	WI	5.2
W/(Q+I)	0.45	CF	70.0
Cement Content	484.1	WF	30.0
		AWF	27.9

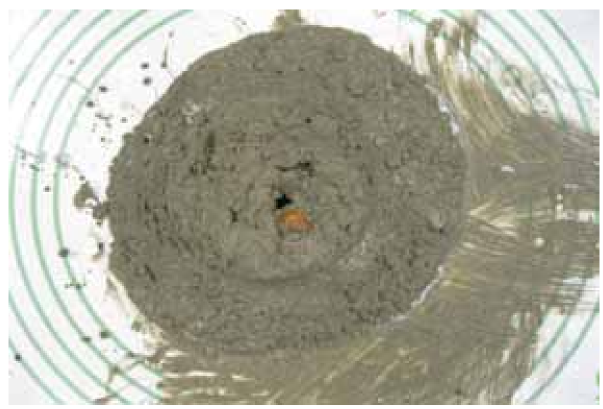
Mix 17.0

Plastic Properties

Slump, in.	3
% Air	3
Paste Volume	22.08
Unit Wt (pcf)	147
Actual w/c	0.45
W/(Q+I)	0.45
Cement Content	484.1

Pre-Vib Slump	2.25
Post-Vib Slump	6.5
Spread Length	13.75
Spread Width	12.25
WI	6.6
CF	50.0
WF	30.0
AWF	27.9

Mix 18.0



Plastic Properties

Slump, in.	3.5
% Air	3
Paste Volume	23.9
Unit Wt (pcf)	145.8
Actual w/c	0.45
W/(Q+I)	0.57
Cement Content	526.4

Pre-Vib Slump	2.50
Post-Vib Slump	7.25
Spread Length	15.25
Spread Width	14.5
WI	8.4
CF	47.5
WF	35.0
AWF	34.0

Mix 19.0

Plastic Properties

Slump, in.	3
% Air	1.75
Paste Volume	22.27
Unit Wt (pcf)	148
Actual w/c	0.45
W/(Q+I)	0.35
Cement Content	484.1

Pre-Vib Slump	3.25
Post-Vib Slump	7.0
Spread Length	13.5
Spread Width	13.5
WI	6.7
CF	70.0
WF	25.0
AWF	22.9

Mix 20.0

Plastic Properties

Slump, in.	2.75	Pre-Vib Slump	2.0
% Air	2.25	Post-Vib Slump	4.75
Paste Volume	22.17	Spread Length	11.75
Unit Wt (pcf)	147.4	Spread Width	11
Actual w/c	0.45	WI	4.4
W/(Q+I)	0.35	CF	50.0
Cement Content	484.1	WF	25.0
		AWF	22.9

Mix 21.0

Plastic Properties

Slump, in.	3	Pre-Vib Slump	2.75
% Air	3.5	Post-Vib Slump	7.5
Paste Volume	23.79	Spread Length	13.375
Unit Wt (pcf)	145.8	Spread Width	14.375
Actual w/c	0.45	WI	7.6
W/(Q+I)	0.71	CF	80.0
Cement Content	526.4	WF	40.0
		AWF	39.0

Mix 22.0

Plastic Properties

Slump, in.	2.75
% Air	4
Paste Volume	23.6
Unit Wt (pcf)	144.2
Actual w/c	0.45
W/(Q+I)	0.71
Cement Content	526.4

Pre-Vib Slump	2.25
Post-Vib Slump	7.50
Spread Length	14.25
Spread Width	13.875
WI	8.0
CF	40.0
WF	40.0
AWF	39.0

Mix 23.0

Plastic Properties

Slump, in.	3
% Air	2.5
Paste Volume	23.32
Unit Wt (pcf)	146.2
Actual w/c	0.45
W/(Q+I)	0.45
Cement Content	512.3

Pre-Vib Slump	2.75
Post-Vib Slump	6.5
Spread Length	14.25
Spread Width	14.25
WI	7.3
CF	40.0
WF	30.0
AWF	28.6

Mix 24.0

Plastic Properties

Slump, in.	2.5
% Air	4
Paste Volume	23.7
Unit Wt (pcf)	144.8
Actual w/c	0.45
W/(Q+I)	0.71
Cement Content	526.4

Pre-Vib Slump	1.75
Post-Vib Slump	6.25
Spread Length	13
Spread Width	14.25
WI	7.2
CF	60.0
WF	40.0
AWF	39.0

Mix 25.0

Plastic Properties

Slump, in.	2.5	Pre-Vib Slump	1.75
% Air	2.25	Post-Vib Slump	4.50
Paste Volume	22	Spread Length	12
Unit Wt (pcf)	146.4	Spread Width	11.5
Actual w/c	0.45	WI	4.7
W/(Q+I)	0.45	CF	60.0
Cement Content	484.1	WF	30.0
		AWF	27.9

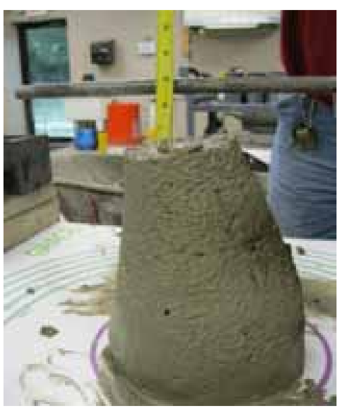
Mix 26.0

Plastic Properties

Slump, in.	2.75
% Air	3
Paste Volume	21.88
Unit Wt (pcf)	145.8
Actual w/c	0.45
W/(Q+I)	0.57
Cement Content	484.1

Pre-Vib Slump	2.00
Post-Vib Slump	5.50
Spread Length	13
Spread Width	13.25
WI	6.2
CF	90.0
WF	35.0
AWF	32.9

Mix 27.0



Plastic Properties

Slump, in.	3
% Air	3.5
Paste Volume	26.07
Unit Wt (pcf)	144.2
Actual w/c	0.45
W/(Q+I)	0.87
Cement Content	578.1

Pre-Vib Slump	2.0
Post-Vib Slump	7.5
Spread Length	14.5
Spread Width	14.5
WI	8.5
CF	60.0
WF	45.0
AWF	45.4

Mix 28.0

Plastic Properties

Slump, in.	3.25	Pre-Vib Slump	4.0
% Air	2.25	Post-Vib Slump	7.0
Paste Volume	22.19	Spread Length	12.25
Unit Wt (pcf)	147.6	Spread Width	12.25
Actual w/c	0.45	WI	5.2
W/(Q+I)	0.45	CF	90.0
Cement Content	484.1	WF	30.0
		AWF	27.9

Mix 29.0

Plastic Properties

Slump, in.	4.5
% Air	2.5
Paste Volume	24.05
Unit Wt (pcf)	146.4
Actual w/c	0.45
W/(Q+I)	0.52
Cement Content	526.4

Pre-Vib Slump	4.0
Post-Vib Slump	8.75
Spread Length	15.25
Spread Width	15.5
WI	8.8
CF	64.5
WF	33.1
AWF	32.1

Mix 30.0

Plastic Properties

Slump, in.	5.5	Pre-Vib Slump	4.25
% Air	2.75	Post-Vib Slump	7.75
Paste Volume	24.66	Spread Length	15.5
Unit Wt (pcf)	146.4	Spread Width	15.5
Actual w/c	0.473	WI	8.3
W/(Q+I)	0.56	CF	59.0
Cement Content	526.4	WF	35.8
		AWF	34.8